

DROP ON DRUM VISION SYSTEM & BENCH TOP MICROSCOPE

ME 493 Final Report – Year 2007

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MECHANICAL ENGINEERING DESIGN TEAM

JEFF CARPENTER
CHARLIE MORRIS
DAVID POSTEL
JEREMY RYATT

ELECTRICAL AND COMPUTER ENGINEERING DESIGN TEAM

REUBEN BELLIKA
VIET BUI

PSU FACULTY ADVISOR
MARK WEISLOGEL, Ph.D.

XEROX INDUSTRY ADVISOR
TREVOR SNYDER, Ph.D.

Executive Summary

The prototypes of the Drop on Drum Vision System (DODVS) and Bench Top Microscope (BTM) have been constructed and are in working condition. The DODVS and BTM will be used by Xerox, Portland State Undergraduate and Graduate students for research of the solid-ink printing process. Specifically, the DODVS will image the ink while on the printer drum and the BTM will image the ink after it has been transfixed to the paper.

All major milestones were met and the end products were completed for their final delivery date of June 6, 2007. The completed systems were evaluated and compared to the product design specification (PDS) determined at the beginning of the project.

- The vibration resistance characteristics of the system have proven to be far superior to the previous DODVS system used at PSU.
- The optic mounting system for the DODVS and BTM has been improved over the previous system by incorporating a dual coarse/fine focus control that is readily accessible.
- The optics has been improved by modifying the current system for the DODVS and purchasing an identical system for the BTM. The improvement provides a magnification that is more than twice of the previous system.
- The BTM is a completely new design that incorporates motorized X-Y stages remotely controlled by a joystick for accurate paper positioning.

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Introduction

Color printers are common in homes and businesses across the globe due to advanced technologies that allow for lower up-front and per-page costs for the consumer. Lower costs, however, do not mean lower quality. The opposite, in fact, is true, especially when considering the solid-ink technology of the Xerox Corporation. Solid-ink technology produces brilliant, vibrant prints on a wide range of media while being easy on the environment with 95% less waste than a typical color laser printer.

The printing occurs using what is actually a simple, robust, and reliable printing mechanism. The process consists of a maintenance roller that applies a microscopic layer of silicon oil to the drum so the ink will release easily, shown in Figure 1. The print head then applies the required color combinations to the drum. The image transfer occurs as the paper is fed between the drum and a transfix roller, shown in Figure 2. The ink bonds to the paper because the ink penetrates the fibers of the paper and solidifies as it cools.

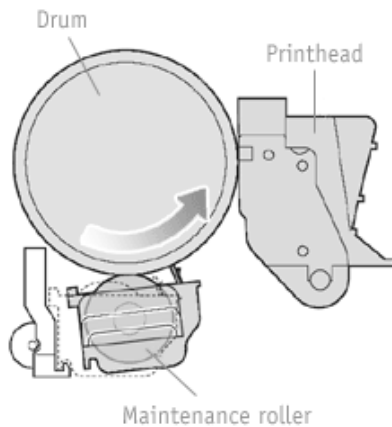


Figure 1: Oil is transferred from the maintenance roller to the drum before ink is transferred by the print head.

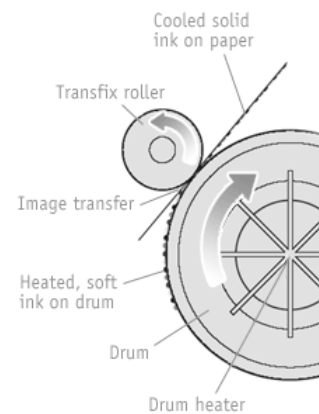


Figure 2: Ink transfer from drum to paper as the paper feeds between the transfix roller and drum.

To maintain the quality of this process, Xerox continually studies, evaluates and explores options for improving the current printers. These studies occur in conjunction with the Mechanical Engineering department here at PSU. In order for improvements to be made, more information needs to be gathered about the characteristics of the individual drops of ink on both the drum and paper. A way to gather this information is through digital images of the individual drops of ink obtained from an optical system. Due to the complexity of removing the drum from the printer, it is advantageous to produce a system that is capable of capturing images of the drops on the drum while the drum is still in the printer and on the paper after the ink has been transferred.

Current systems used for imaging fail to meet the requirements of Xerox. The previous system in use at PSU was seen to be clumsy to use, with excessive vibration and poorer-than-desired image quality. Another system in use at the Xerox campus in Wilsonville does not have the printer located in a specific spot, making repeatability of image location hard to achieve. There is no imaging system specific to the paper for comparing the drum images to paper images. Due to these shortcomings, there was a need by Xerox and their collaborators at PSU for a newly designed imaging system for the printer drum and paper to enable research to improve solid-ink printers.

Mission Statement

The team will design, manufacture and test a new Drop on Drum Vision System (DODVS) and Bench Top Microscope (BTM) that meet the design requirements established by Xerox for its research. The DODVS and BTM will be used to examine the transfixion of ink to the drum and paper with improved vibration resistance, image quality and accuracy compared to the previous imaging systems. The expected date of completion and testing is set for June 2007.

Project Planning Document

To meet the June 2007 completion date, all of the tasks and their associated due dates were established in a Gantt chart, shown in Figure 3. The chart lists important milestones for the project such as ME 492/493 requirements and DODVS/BTM design requirements.

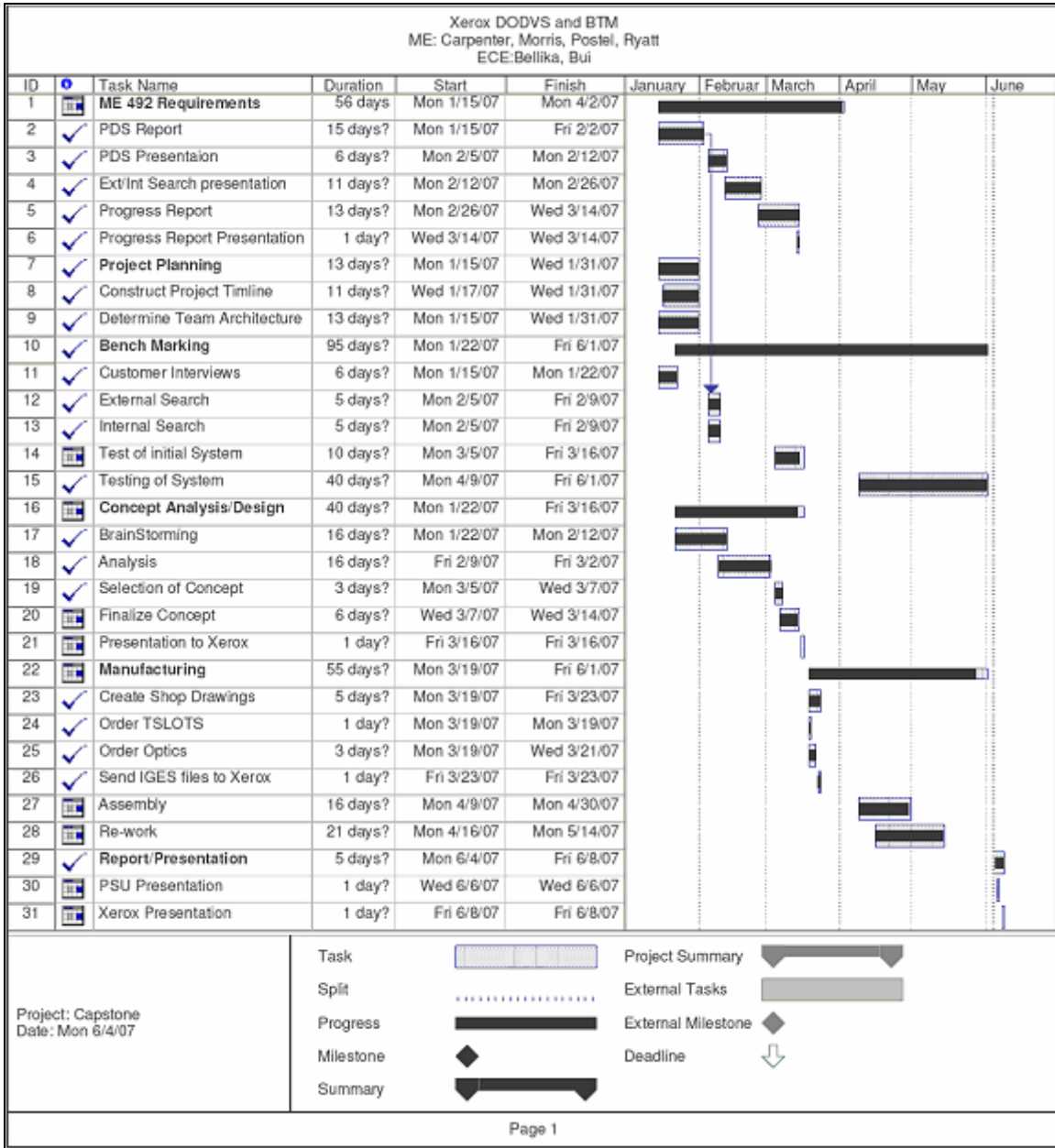


Figure 3: Project timeline.

Product Design Specification

~ PERFORMANCE ~						
Requirements	Primary Customer	Metrics & Targets	Metric	Target	Target Basis	Verification
Image Quality	Xerox	Viewing area	inches	1/600 in^2	Customer Defined	Prototyping
Vibration resistance	Xerox	Time of oscillation	seconds	0-1 second	Customer Defined	Prototyping
Table speed (BTM)	Xerox	Table traverse speed	in/min	> 1/3 in/min	Group Decision	Prototyping
Position Locating	Xerox/Operator	Position of printer vs DODVS	inches	0-1/64 in	Customer Defined	Prototyping
Adjustability	Xerox	Adjusting Z-location of camera	inches	1/64 in	Group/Customer	Prototyping
Reliability	Xerox/ Operator	Time until part failure	Years	5 yrs	Customer Defined	Prototyping

~ SAFETY ~						
Requirements	Primary Customer	Metrics & Targets	Metric	Target	Target Basis	Verification
Finger Guard	Xerox Legal Department	Guard fingers from moving platform	N/A	Shroud	Group Decision	Prototyping

~ ENVIRONMENT and ERGONOMICS~						
Requirements	Primary Customer	Metrics & Targets	Metric	Target	Target Basis	Verification
Withstand operation in a Lab environment	Xerox	Needs to withstand constant adjustment	Years	5 Years	Customer Defined	Time will tell
Sit side-by-side on a table	Xerox/Operator	Minimal distance between units	feet	< 1 foot	Customer Defined	Set-up
Aesthetics	Operator	Clean, Streamlined look and feel	N/A	N/A	Group Decision	Post interview
Portability	Xerox/Operator	Weight	Pounds	< 75 lbs/piece	Group Decision	Prototyping

~ MAINTENANCE and PARTS ~						
Requirements	Primary Customer	Metrics & Targets	Metric	Target	Target Basis	Verification
Part Replacement	Xerox/ Operator	Off-the-shelf parts	N/A	Readily available	Group Decision	Market research
Fasteners	Operator	Assembled using standard parts	Inches	Standard Tools	Group Decision	Prototyping
Manufactured Parts	Xerox Prototype Shop	Standard Materials	N/A	In stock material	Group Decision	Stock List, Appendix B

~ INSTALLATION ~						
Requirements	Primary Customer	Metrics & Targets	Metric	Target	Target Basis	Verification
Withstand occasional relocation	Xerox/Operator	Can be disassembled and assembled by one person	Minutes	45 minutes	Customer Defined	Experiment
Electricity source	Operator	Outlet	VAC	120 VAC	Group Decision	Prototyping
Level of table	Xerox/Operator	Level	degrees	±0.25°	Group Decision	Prototyping

~ COST ~						
Requirements	Primary Customer	Metrics & Targets	Metric	Target	Target Basis	Verification
Low production cost	Xerox	Cost	Dollars	< \$5,000.00	Customer Defined	BOM/Invoices

Top Level Design

Overview

In order to come to the final design decisions, there were many problems with the previous system that needed to be evaluated before manufacturing began. For instance, the previous mount for the DODVS camera was cumbersome and inefficient; therefore, this had to be redesigned to swing out of the way to allow easy access to the inside of the printer for adjustments. The BTM camera mount was designed from the ground up in order to have a dual coarse/fine focus stage; this was necessary to provide the crucial image requirements established by Xerox.

To eliminate vibrations caused by the original frame designs, the new versions were constructed of more massive and rigid materials. Both the DODVS and BTM consist of thick top and base plates along with two extruded aluminum supports. This design increases the natural frequency of the system while making deflection caused by the movement of the linear translation stage negligible.

When evaluating our positioning stages it was concluded that it was necessary to have a minimum step of $42\mu\text{m}$. The previous linear stage for the DODVS satisfied this requirement enabling us to reuse it to cut down on cost. The BTM uses no positioning of the camera, instead it remains stationary while the paper is positioned in respect to the camera using an X-Y stage donated by Xerox having a minimum step of $28\mu\text{m}$, surpassing our PDS requirements. For ease and versatility the stage can be controlled electronically by the joystick control interface along with hand cranks for finer adjustments.

The optics in the previous system did not provide enough magnification to meet the required specifications. To meet these specifications without exceeding our budget the old lens assembly was modified to use a higher magnification TV tube, and an auxiliary lens was added. To have a one to one comparison between the paper image and printer drum image an identical system was bought for the BTM.

For lighting is concerned, the original system had Schott goosenecks which were found to be stable but still did not provide sufficient lighting. The gooseneck did not provide focusing of the light output. As a result a pair of focusing lenses for the goosenecks was purchased to solve the lighting issue.

Optic Mounting Assemblies

DODVS Mount

The analysis of the current DODVS system in use at PSU showed that the optic mounting assembly needed to be redesigned. The redesign was required due to two key shortcomings: ease of use and z-location control to meet resolution requirement and focusing.

To improve ease of use, the new design allows for the mount to swing the lens assembly to the side, out of the printer, as shown in Figure 4. This is important because the lid needs to be shut on the printer to print properly after the ink on the drum has been analyzed.

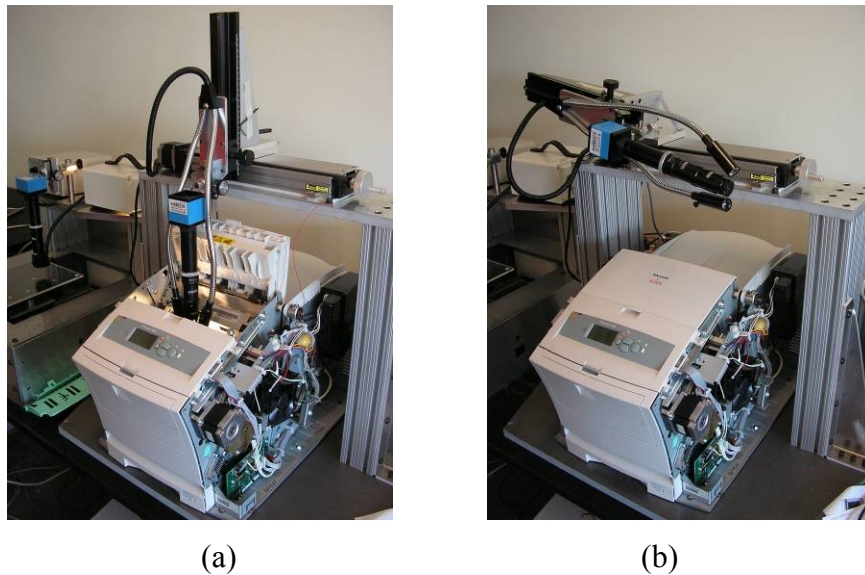


Figure 4: (a) Optic Mount in operating position. (b) Optic mount with lens moved out of the way.

To improve the quality of images, the focal length for the lens assembly and focus control was taken into consideration. To provide a wide range of control, a long travel stage was incorporated with a dual coarse/fine focusing stage from Edmunds Optics (figure 5). The

long travel stage allows for imaging from a greater distance or for easily adapting the lens assembly with different length lenses.

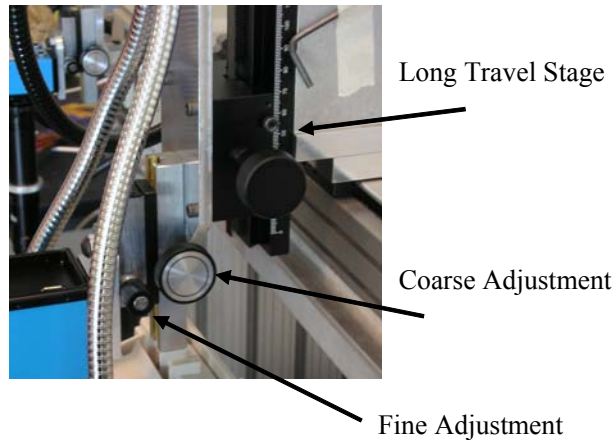


Figure 5: Stages used for greater focal length control of optic assembly.

BTM Mount

The entire BTM was essentially designed from the ground up to provide a device for taking images of the ink once it has been transfixed to the paper. To mount the optics assembly, the same dual coarse/fine focus stage was used with adapters being designed and manufactured to allow for its use. The BTM optic mount is shown in Figure 6.

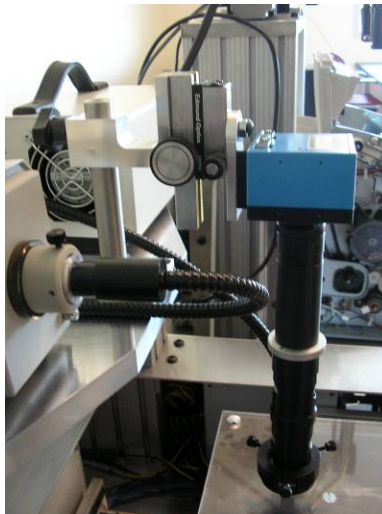


Figure 6: BTM optic mount assembly.

Frames

To meet the PDS specifications, two frames were constructed: one for the DODVS and the other for the BTM. The main frame requirements were vibration resistance and simple assembly and disassembly. System accuracy and machinability also influenced the designs. Vibration analysis of the old system and various alternatives determined that the best design for both frames consisted of a heavy base plate, two cantilever vertical members and a top mounting plate. Both the DODVS and BTM frames use a similar construction.

DODVS frame

The DODVS Frame consists of a $\frac{3}{4}$ -inch-thick aluminum base plate, two 3×6 inch T-Slot vertical members from 80/20 and a second $\frac{3}{4}$ inch top plate. Also, angular gussets are attached to the vertical members and the base plate to increase rigidity. The vertical members are secured to the top and bottom plates by 36-5/16 hex head button cap screws, as seen in Figure 7.

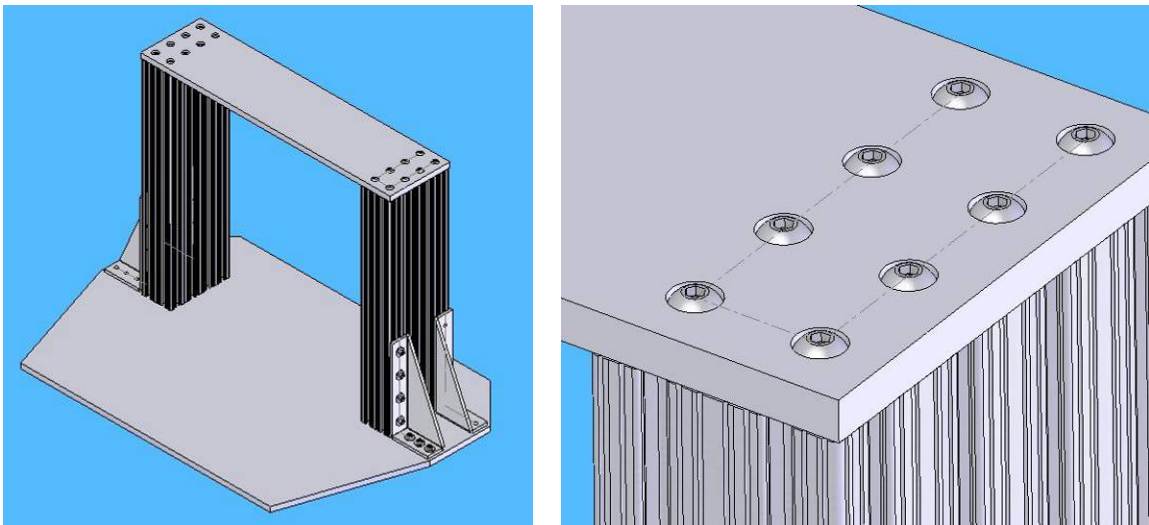


Figure 7: DODVS frame constructed of 3×6 inch T-Slot uprights, mounted to $\frac{1}{2}$ inch thick top and bottom plates, and dual gussets. A close-up of the mounting of the top plate can be seen on the right.

A full ANSYS vibration simulation was performed on some of the most promising initial configurations and the above configuration exhibited the most vibration resistance and highest natural frequency. Refer to Appendix D for more information on the results of the ANSYS simulation.

BTM Frame

The BTM frame uses a similar construction to the DODVS, to make the units match. The frame is constructed of a $\frac{3}{4}$ inch thick aluminum base, and uses the same 3x6 inch T-Slot material for the vertical supports. The BTM uses a stationary camera and both X and Y axes are applied directly to the paper mounting plate. The paper mounting plate is securely bolted to the XY platform, and utilizes magnets to hold the paper in place. The BTM frame assembly can be seen in Figure 8.

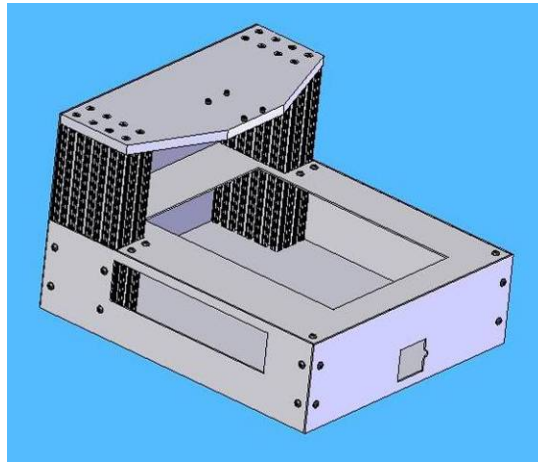


Figure 8: BTM frame assembly.

Side cover plates are installed to conceal stage automation and enclose electrical control components for both the BTM and the DODVS, in addition to increasing rigidity of the frame.

Stages

For the DODVS, the original linear translation stage was reused for two reasons: it met the requirements of the PDS with a minimum step of $21\mu\text{m}$ and cost nothing. A new translation stage would have cost at least \$700.00, which would have put us well over our \$5000.00 budget. The DODVS translation stage is shown in Figure 9.

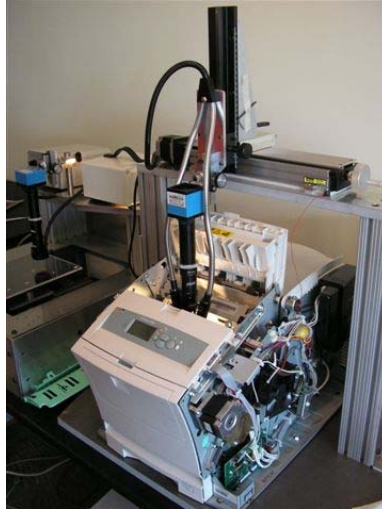


Figure 9: Linear translation stage used on DODVS with camera and adjust stages attached

The X-Y stage used for the BTM was donated to us by Xerox which kept us under budget. The minimum step that either the X or Y stage can take is $28\ \mu\text{m}$, which is significantly more precise than was specified in the PDS ($42\ \mu\text{m}$). After the step precision of the stage was verified it was taken apart, thoroughly inspected and prepared for use by cleaning it and re-lubricating the bearings. The platform can be controlled manually via hand cranks or electronically by the joystick control interface. The details of the control system are given below.

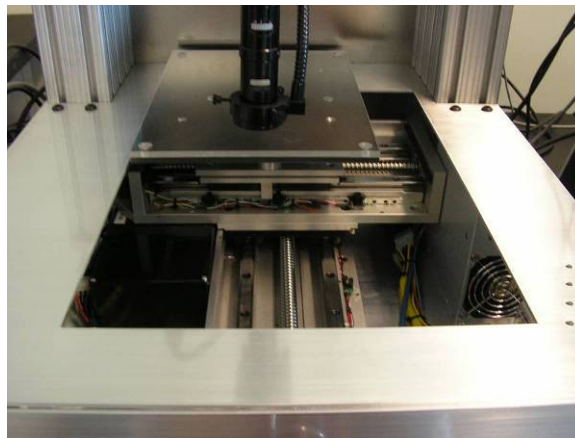


Figure 10: XY stage used on BTM.

The paper hold-down that is mounted on top of the X-Y stage consists of a steel plate with an acrylic plate over it. A sheet of paper is placed on the acrylic and niobium magnets are placed on the paper, which secure it to the paper hold-down. The acrylic

plate was used for surface smoothness. If the paper were exposed directly to the steel plate, the plate would have to be painted to prevent oxidation and any inconsistencies in the paint could elevate the paper in an undesired manner, which could affect the quality of the images taken.

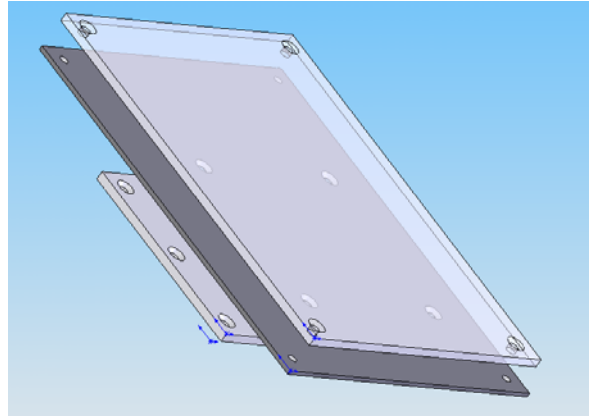


Figure 11: Paper hold-down for BTM: Acrylic plate, Steel plate and stage mounting interface

Optics

The optics are the core components that capture the image from the drum or paper, namely a variable magnification lens assembly and a CCD camera. The previous DODVS used a Thales-Optem 70XL modular lens assembly and an Imaging Source DFK 31F03 Firewire camera. Since this was a redesign and funds were limited, the changes to the optics were limited to relatively modest modifications to the existing equipment. The previous system did not provide enough magnification to meet specifications, so the old lens assembly was modified to use a higher magnification TV tube and an auxiliary lens was added. This increased magnification from the 1.5X – 10.7X range to the 3.0X – 21.8X range. This change also had the benefit of increasing the resolving power of the system from a minimum feature size at maximum magnification of 5.3 μm with the old system to 2.7 μm with the current system (see Appendix D for calculations). The camera has sufficient resolution for the application, so it was retained.

The choice of optical components, although necessary to meet requirements, had an important impact on the design of the mechanical components. The higher resolution optical system has a maximum working distance of 32 mm, as compared to the 89 mm working distance of the old system. This required a redesign of the optic mount for the

DODVS, due to the tight clearances inside the printer, although it was not really an issue with the BTM.

One of the design objectives was to have identical optical systems between the DODVS and the new BTM. To this end, after preliminary verification of the improvements from the modifications to the lens assembly, an identical lens assembly and camera were purchased for use with the BTM. Due to availability, a newer camera model, the DFK 31AF03, had to be substituted. The specifications of this model are the same as the old camera, although it is physically smaller. This required the fabrication of an additional mounting plate for the new camera, but otherwise did not affect the design.

Lighting

There were two problems with the original gooseneck lighting system. First, the time to dampen out any induced vibration was beyond acceptable values. Second, the amount of light required was insufficient at maximum magnification due to the working distance (89 mm) of the lens. After much research and hands-on testing, Schott goosenecks were determined to be stable but still did not provide sufficient lighting. The gooseneck did not provide focusing of the light output. As a result; a pair of focusing lenses for the goosenecks was purchased.

For the BTM system the same lighting system as the DODVS was desired so there is no discrepancy in the color temperature and intensity. Unfortunately, the lighting system design for the BTM system had to be changed due to the request of our sponsor. The request was to use ring lighting for ease of setup and minimal adjustment required. Before doing so a series of comparative testing were done to eliminate any discrepancy in image quality.

Lighting configuration results:

DODVS: Schott Gooseneck
BTM: Schott Mini Ringlight

Test setup:

System 1	System 2
<ul style="list-style-type: none"> • Lighting system: Schott Combination Dual Goosenecks w/ Bundle (A08520) • Light Source: Dolan-Jenner PL-800 (100% intensity level) • Optics: Thales Optem XL70, 2X TV, 2X Aux lens (Iris completely opened) • Test Sample: US 5 dollar bill 	<ul style="list-style-type: none"> • Lighting system: Schott Mini Ringlight • Light Source: Dolan-Jenner PL-800 (100% intensity level) • Optics: Thales Optem XL70, 2X TV, 2X Aux lens (Iris completely opened) • Test Sample: US 5 dollar bill

Test Results








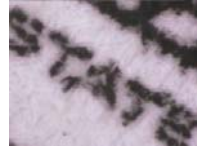

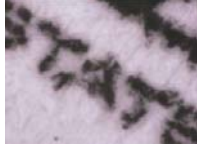




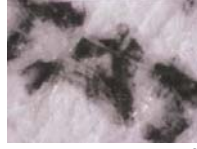

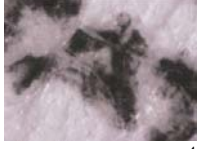

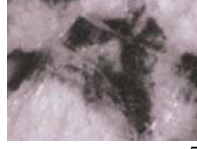





Goosenecks	Ring	Goosenecks	Ring
			
1.0X		1.25X	
			
1.50X		1.75X	
			
2.0X		2.5X	
			
3.0X		3.5X	
			
4.0X		5.0X	
			
6.0X		7.0X	

Fig. 4. Five dollar bill sample. When comparing goosenecks and ring lighting image quality and brightness, there are minimal differences.

Motion Controls

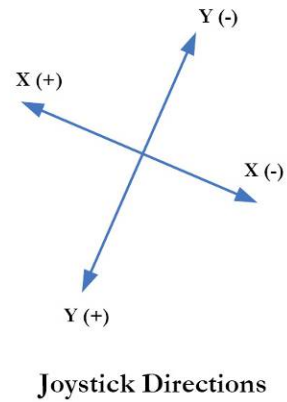
The motion controls are the electronic systems used to position the optics of both the DODVS and BTM. The DODVS is controlled through software on the computer, while the BTM is controlled with a joystick. Both are described below.

DODVS Control

To be able to image different portions of the drum, the optics are mounted on a Parker linear ballscrew stage with a stepper motor and motion controller. This controls motion along the axis of the drum and is considered the X axis. The Y axis is the rotational axis of the drum, which is controlled through the printer operating system. The motion on these axes is coordinated through a Motion Console program written as part of the previous project. This program has been modified to correctly locate the desired position on the drum and to accommodate the fact that the current optics limit the range of travel in the X direction. Although replacing the stage and controller were considered, the resolution was deemed sufficient, though not ideal, for the application. This, in combination with limited funds and time, led to the decision to retain the existing motion control system for the DODVS.

BTM Control

The BTM setup composes of two linear ballscrew stage with a stepper motor and driver. For portability and simplicity a microcontroller was used to send step and direction to each stage. The input for the microcontroller comes from a joystick. Depending on the rotation of the joystick the rotation speed of the stepper motor can go from slow to fast. Integrated onto the joystick is a remote power button for the power supply. When the system is on, the rows of LED indicates directional 'up' and system is powered.



Design Evaluation

Optic Mounting Assemblies

The optic mounting assemblies exceeded the product design specification in performance for z-location adjustment. A requirement of 1/64 in (0.4 mm) was specified in the PDS. The dual coarse/fine movement stage from Edmund Optics provides 15mm of coarse adjustment per knob revolution and 0.11 mm of fine adjustment per knob revolution. This provides a fine adjustment better than the requirement.

It was important for the optic mounting assemblies to also meet the product design specifications for maintenance and parts. The movement stages purchased from Edmunds Optics are standard stock and can be used directly out of the box with no modification. All fasteners are standard sizes and readily available. The parts that were required to be manufactured for the mounting assembly were made from standard stock aluminum and could be made from virtually any material; aluminum was selected for its low weight and ease of machine ability.

Frames

The primary PDS specifications for both the DODVS and BTM frames are vibration resistance, durability, size, aesthetics, portability, use of standard parts, and single person assembly. Both the BTM and the DODVS exceed all but one of the PDS specifications

by a wide margin. The PDS specification for portability required that both frames weighed less than 75 pounds each. This weight was intentionally exceeded with approval from the industry sponsor by using the more robust $\frac{3}{4}$ " base plate, which raised the overall weight of both units to 83 lbs. Despite failing to meet the desired specification, both frames are portable by two persons and can be easily disassembled to become portable by one person if necessary.

Stages

The stages are a key component to the quality of research performed and we are proud to say that both stages, exceed the requirements specified in the PDS last fall. The XY platform used on the BTM has a minimum travel distance of $28\mu\text{m}$ for both axes, which is a finer resolution than the $42\mu\text{m}$ specified in the PDS. The maximum speed of both axis of the table also exceeds the $1/3'$ /per minute specified, while also being able to move one motor step at a time, depending on the setting of the control system.

The linear translation stage used on the DODVS also exceeds the requirements specified in the PDS, with its minimum step of $21\mu\text{m}$ and maximum translation speed $4''$ per second, while also being able to move one step at a time.

Optics

The main PDS requirement relating to the optics was to obtain a viewing area of $1/600''$ on the side. This was not practically obtainable within our budget, and discussions with our sponsor indicated that this requirement could be relaxed. The changes to the optical system did, however, result in improvements both in magnification range and resolution.

The optics improvements were evaluated by taking pictures of ink on the drum using both the old and new DODVS. Since the maximum magnification can be more than doubled, the difference in magnification is apparent. An image of similar formations at the same magnification for each system is shown in Figure 14.

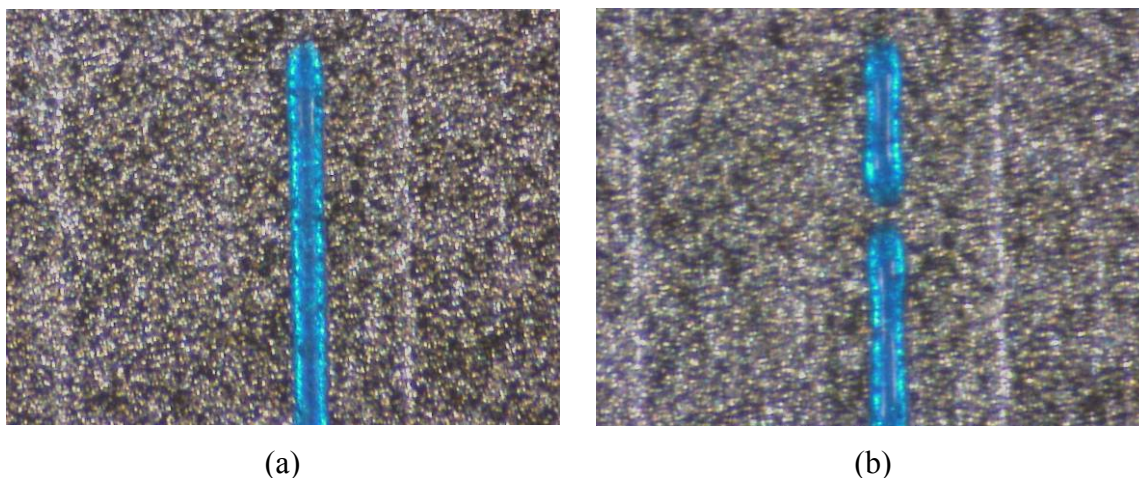


Figure 14: (a) Line image at 7x with new DODVS. (b) Line image at 7x with old DODVS.

As can be seen from the images, the new system provides better resolution and less blurring due to vibration than the old system. The magnification range is also greater with the introduction of the 2X auxiliary lens. A more extensive series of image comparisons is given in Appendix E.4.

Lighting

The whole intension of redesigning the lighting system was to achieve higher output and reduce vibration. This was achieved by adding a focusing lens to the gooseneck and decreasing the working distant. Also the image capturing software was upgraded to enable additional functionality such as, noise reduction, brightness control, and shutter speed. Images were taken from the old system versus the new system and shows improvement.

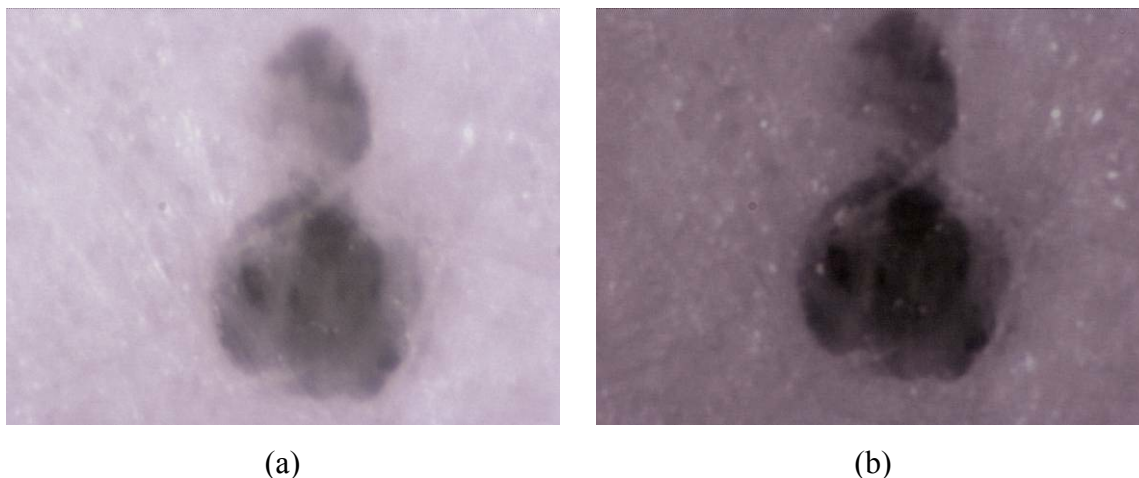
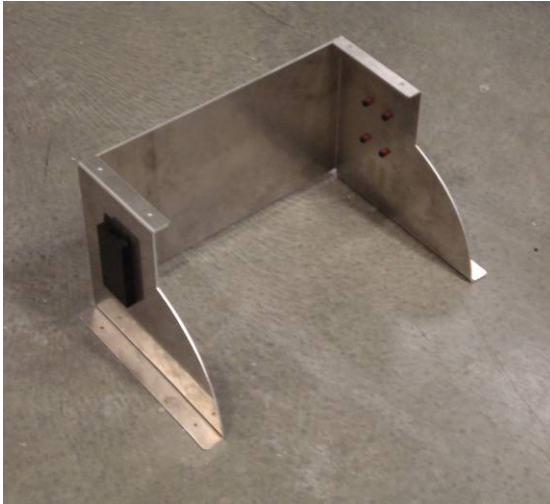


Figure 15: (a) 1/600" square created in Photoshop viewed at 22X with new lighting system. (b) 1/600"

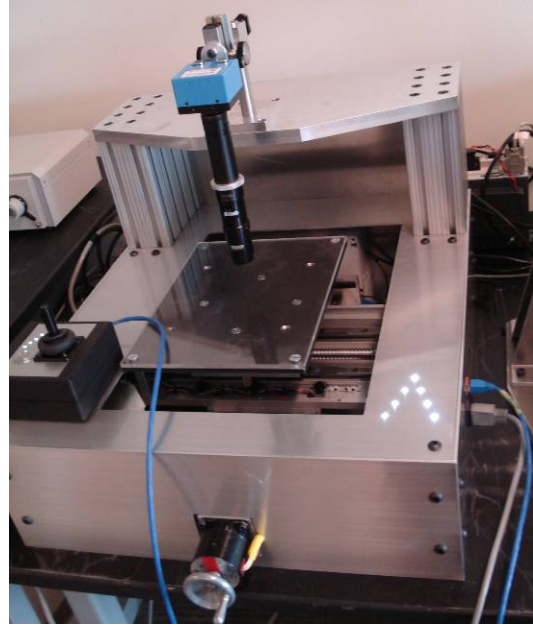
square created in Photoshop viewed at 22X with old lighting system.

Motion Controls

Motion controls for the BTM was none existence before the project had started. The need to manually move the object was eliminated due to the introduction of motorized X-Y stages. The stepper motor in combination with a fine pitch thread allowed for accurate movement at 21 μm per step. This level of accuracy is beyond any human precision.



(a)



(b)

Figure 16: (a) Old BTM system consisted of only a frame. (b) New BTM with X/Y stage.

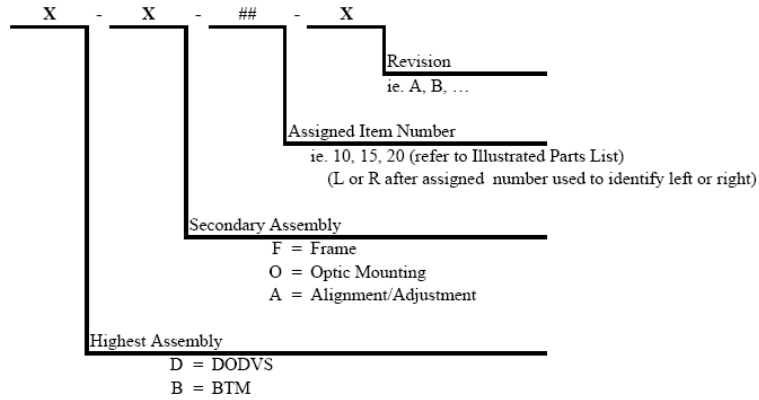
Conclusion

The quality and performance of the new DODVS and BTM are satisfactory following testing and evaluation. With most of the target goals established in the PDS met or exceeded, the systems can be presented to the Xerox Corporation as finished products. The DODVS system has significantly better vibration resistance as seen in comparison at the maximum 10X zoom from the old system and a similar zoom of the new system. The new system does not demonstrate the magnitude of oscillation that the old system did. Even at the new DODVS maximum zoom of 22X, there is less vibration than the previous DODVS at 7X (based on picture clarity with the noise reduction system turned off). The new BTM system is a more useful system than the previous BTM, which was a bent piece of sheet metal. The new BTM is motorized, with two rapid traverse speeds for

the X-Y stage and the ability to move the stage using joystick control. The system is controlled by a user-friendly control interface that can be used remotely up to six feet. The most important PDS criteria that were met are the vibration resistance and the image quality. The new DODVS has a much more rigid frame with a higher natural frequency and both systems can take images with side lengths down to 5/600”.

As stated before, the systems designed and built by the capstone team exceeds the capabilities of the original systems. With these new research tools, students at Portland State University will be able to collect more precise data and in turn help with the development of the next generation of Xerox solid ink printers.

Appendix A: Manufacturing Assembly

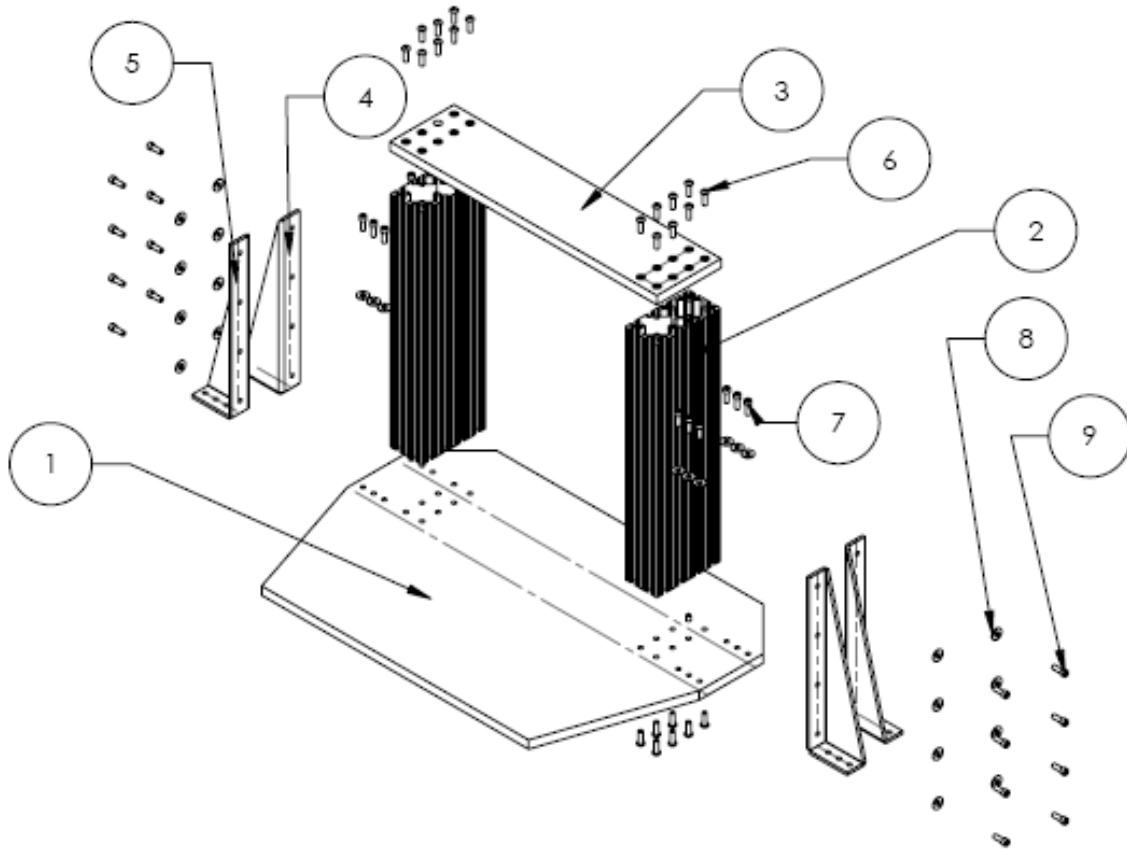


Example of part numbering for manufactured parts

DO10A = DODVS, Optic Mounting, Base Plate, Revision A

Parts purchased and used without any modification use vendor part numbers

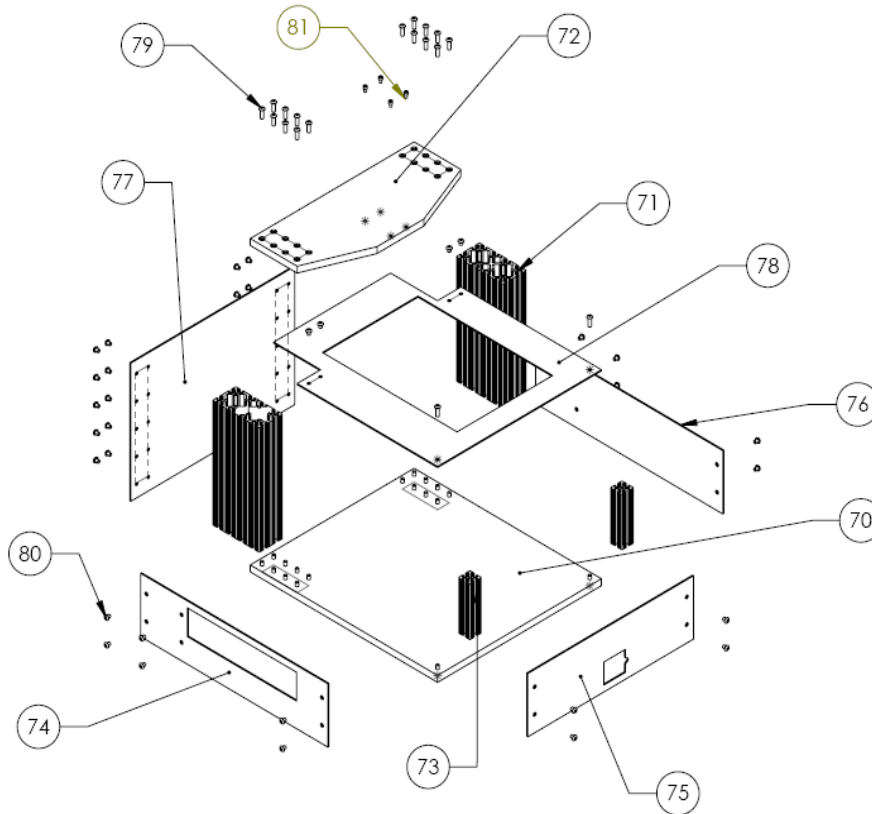
DODVS Frame Assembly



DODVS Parts List

ITEM	PART NUMBER	NOMENCLATURE	SPECIFICATION	QTY	VENDOR
1	DF01A	Base Platform	$\frac{3}{4}$ inch thick aluminum plate	1	Xerox
2	DF02A-3060	Vertical Support	3060 Extruded aluminum	2	80/20
3	DF03A	Top Plate	$\frac{3}{4}$ inch thick aluminum plate	1	Xerox
4	DF04A	Gusset LH	$\frac{1}{4}$ inch aluminum sheet	2	Xerox
5	DF05A	Gusset RH	$\frac{1}{4}$ inch aluminum sheet	2	Xerox
6	91255A581	Screw. Secures base and top plate to vertical supports.	$\frac{5}{16}$ -18 button hex head socket cap screw $\frac{3}{4}$ inches long.	32	McMaster-Carr
7	91251A381	Screw. Secures gusset to base platform.	$\frac{5}{16}$ -24 Socket cap screw $\frac{3}{4}$ inch long.	12	McMaster-Carr
8	91083A030	Washer. All gusset screws.	$\frac{5}{16}$ plain flat washers	28	McMaster-Carr
9	3278, or 3311, or 3282	Bolt and Nut	T-Slot special bolt and nut assembly	16	80/20

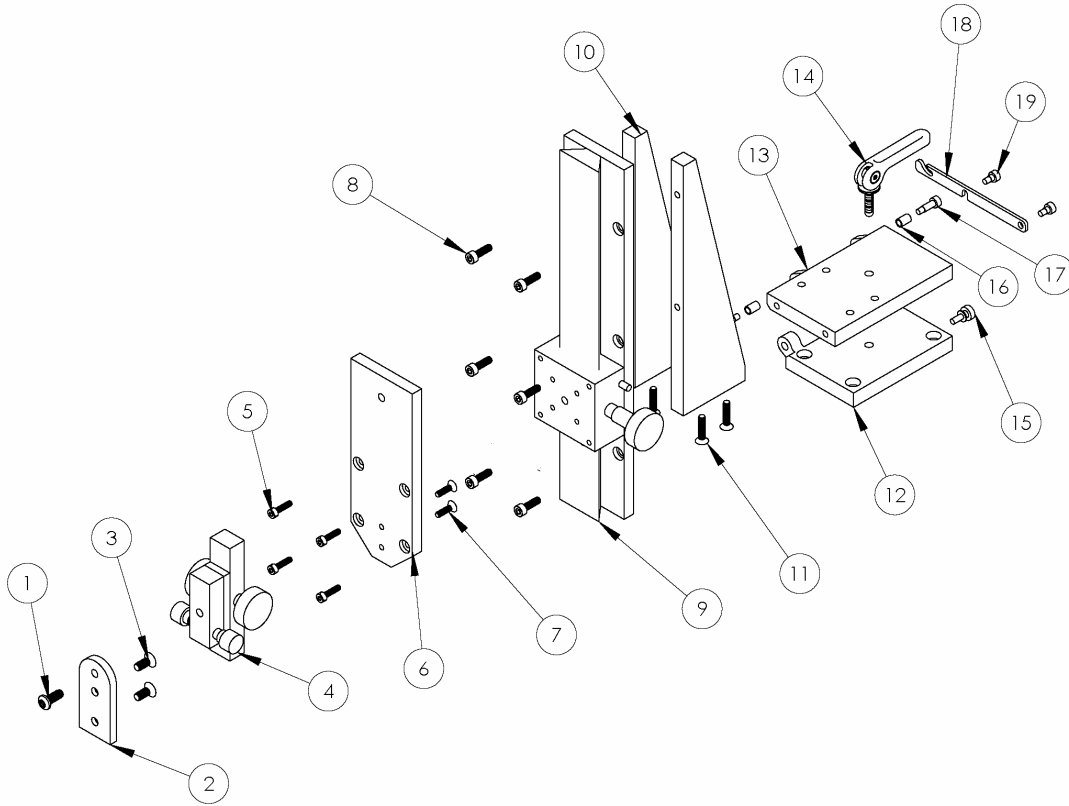
BTM Frame Assembly



BTM Parts List

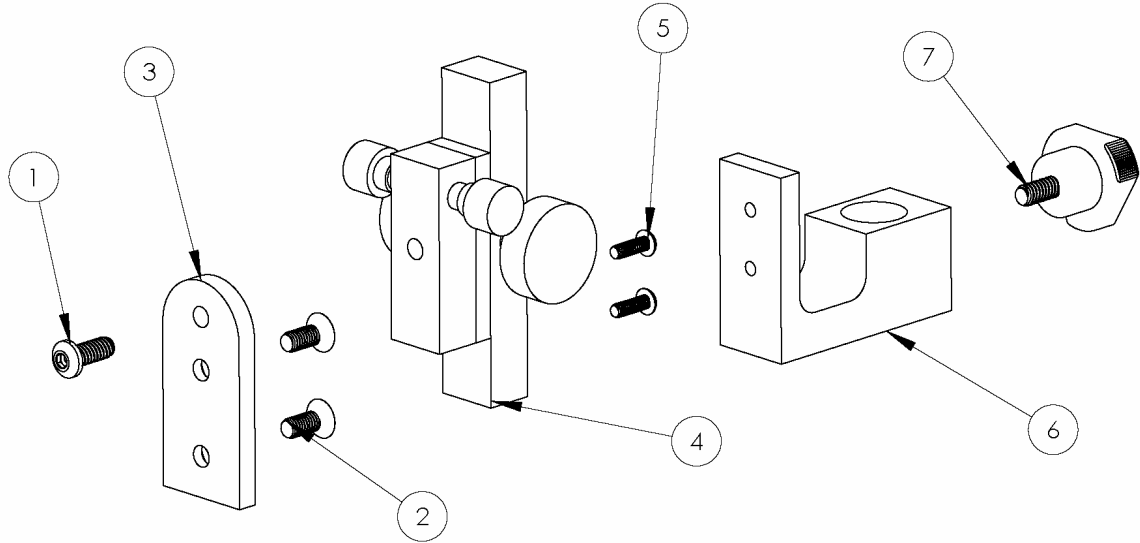
ITEM	PART NUMBER	NOMENCLATURE	SPECIFICATION	QTY	VENDOR
70	BF70A	BTM Base Plate	¾ inch thick aluminum plate	1	Xerox
71	BF71A-3060	BTM Vertical Support	3060 Extruded aluminum	2	80/20
72	BF72A	BTM Top Mounting Platform	¾ inch thick aluminum plate	1	Xerox
73	BF73A-1515	BTM Corner Support	1515 Extruded aluminum	2	80/20
74	BF74A	LS Cover Plate	1/8 thick aluminum plate	1	Xerox
75	BF75A	Front Cover Plate	1/8 thick aluminum plate	1	Xerox
76	BF76A	RS Cover Plate	1/8 thick aluminum plate	1	Xerox
77	BF77A	Back Cover Plate	1/8 thick aluminum plate	1	Xerox
78	BF78A	Top Cover Plate	1/8 thick aluminum plate	1	Xerox
79	91255A581	Button Cap Screw Secures Vertical Members to Plates.	5/16-18 UNC Hex Head Button Cap Screw ¾ Inch Length.	32	McMaster Carr
80	3278, or 3311, or 3282	5/16 80/20 Captive Nut and Bolt	Special T-Slot Captive nut and bolt.	40	80/20
81	91251A539	Screw Secures Camera Mount to Top Plate	¼-20 UNC Hex Head Socket Cap Screw	4	McMaster Carr
Not Shown	4303	Angle Bracket Attaches Cover to Vertical Support	4 Hole Angle Bracket from 80/20.net	2	80/20

DODVS Optic Mount Assembly



ITEM	PART NUMBER	NOMENCLATURE	SPECIFICATION	QTY	VENDOR
1	91255A539	Screw	1/4-20 Thread	1	McMaster Carr
2	D030A	Camera Mount	6061 Al	1	Xerox
3	91294A237	Screw	M6x14, CSK	2	McMaster Carr
4	NT37-603	Dual Coarse/Fine Focus Stage		1	Edmunds Optic
5	91290A154	Screw	M6x14	4	McMaster Carr
6	D040A	Stage Mount Adapter	6061 Al	1	Xerox
7	91253A196	Screw	8-32, CSK	2	McMaster Carr
8	91290A232	Screw	M5-16	6	McMaster Carr
9	NT56-798	250mm Travel Stage		1	Edmunds Optic
10	D050A	Support Angle	6061 Al	2	Xerox
11	91294A215	Screw	M5-22, CSK	4	McMaster Carr
12	D010A	Base Plate	6061 Al	1	Xerox
13	D020A	Top Plate	6061 Al	1	Xerox
14	CL-4-EXP-0.75	Expanding Pin Cam Handle	1/4 x 0.75	1	Carr Lane
15	99607A135	Thumbscrew	8-32 x 1/2	1	McMaster Carr
16	6391K125	Bushing	3/16 x 1/4OD	2	McMaster Carr
17	93996A721	Shoulder Bolt	4-40 x 7/16	2	McMaster Carr
18	D060A	Support Rod	6061 Al	1	Xerox
19	94035A201	Shoulder Bolt	8-32 x 1/2	2	McMaster Carr

BTM Optic Mount Assembly



ITEM	PART NUMBER	NOMENCLATURE	SPECIFICATION	QTY	VENDOR
1	91255A539	Screw	1/4-20 Thread	1	McMaster Carr
2	B010A	Camera Mount	6061 Al	1	Xerox
3	91294A237	Screw	M6x14, CSK	2	McMaster Carr
4	NT37-603	Dual Coarse/Fine Focus Stage		1	Edmunds Optic
5	91255A194	Screw	8-32 x 1/2	2	McMaster Carr
6	B020A	Stage Mount	6061 Al	1	Xerox
7	57715K42	Knob	1/4 x 20 3 arm	1	McMaster Carr

Appendix B: Bill of Materials

A	B	Part #	Name	Catalog Number	Length	Width	Type	Vendor	Invoice #	QTY	Pack	Price	Total
1		18	Back Plate	65752	21	20	AL	XEROX FAB SHOP	X2	1	1	\$0.00	\$0.00
2		17	Base Plate	65750	21	24	AL	XEROX FAB SHOP	X2	1	1	\$0.00	\$0.00
3		19	BTM Optic Mount	65758	2	4	AL	XEROX FAB SHOP	X2	1	1	\$0.00	\$0.00
4		12	BTM Top Cover	65742	21	24	AL	XEROX FAB SHOP	X1	1	1	\$0.00	\$0.00
5		11	BTM Top Plate	65741	6	21	AL	XEROX FAB SHOP	X1	2	1	\$0.00	\$0.00
6		1	DODVS Baseplate	65651	21	24	AL	XEROX FAB SHOP	X1	1	1	\$0.00	\$0.00
7		2	DODVS Top Plate	65654	6	21	AL	XEROX FAB SHOP	X1	2	1	\$0.00	\$0.00
8		15	Front Plate	65747	6	21	AL	XEROX FAB SHOP	X2	1	1	\$0.00	\$0.00
9		3	LH Gusset	65655	12	4	AL	XEROX FAB SHOP	X1	2	1	\$0.00	\$0.00
10		14	LH Plate	65746	6	21	AL	XEROX FAB SHOP	X2	1	1	\$0.00	\$0.00
11		16	Light Adapter	65749	2	3	AL	XEROX FAB SHOP	X2	4	1	\$0.00	\$0.00
12		6	Optic - Bottom Plate	65659	3	1.5	AL	XEROX FAB SHOP	X1	1	1	\$0.00	\$0.00
13		8	Optic - Camera Mount	65661	6	2.5	AL	XEROX FAB SHOP	X1	2	1	\$0.00	\$0.00
14		7	Optic - Stage Adpapter	65660	1	3	AL	XEROX FAB SHOP	X1	1	1	\$0.00	\$0.00
15		5	Optic - Top Plate	65658	6	21	AL	XEROX FAB SHOP	X1	2	1	\$0.00	\$0.00
16		9	Optic Support Angle	65662	3	7	AL	XEROX FAB SHOP	X1	2	1	\$0.00	\$0.00
17		10	Optic Support Rod	65663	0.25	4	AL	XEROX FAB SHOP	X1	1	1	\$0.00	\$0.00
18		4	RH Gusset	65656	12	4	AL	XEROX FAB SHOP	X1	2	1	\$0.00	\$0.00
19		13	RH Plate	65744	6	24	AL	XEROX FAB SHOP	X2	1	1	\$0.00	\$0.00
20		78	Support Brackets	NA	2	2	AL	PSU FAB	P1	2	1	\$0.00	\$0.00
21		31	100K ohm	83F1767			E	Newark	10	20	1	\$0.39	\$0.39
22		37	11-Pin Std Octal Relays	850-2091			E	Allied Electronics	10	2	1	\$3.02	\$3.02

23		20	ARMmite Evaluation Kit	AM-KT			E	Coridium Coporation	2	1	1	\$59.00	\$59.00
24		21	ETI Systems Joystick, 4 Way, Push Button	J4-00212			E	Allied Electronics	2	1	1	\$132.57	\$132.57
25		33	IEC Power Connector	84K0259			E	Newark	10	2	1	\$1.70	\$1.70
26		27	Insulated spade terminal	7869K61			E	McMaster Carr	3	1	1	\$1.96	\$1.96
27		28	LM348N Opamp	07B6547			E	Newark	10	4	1	\$1.38	\$1.38
28		36	Magnetic Latching Relay AC	850-0509			E	Allied Electronics	10	1	1	\$12.19	\$12.19
29		35	Magnetic Latching Relay DC	850-0506			E	Allied Electronics	10	1	1	\$11.57	\$11.57
30		23	Multiple Flux Cores tin/lead with rosin flux	7745A3			E	McMaster Carr	3	1	1	\$37.63	\$37.63
31		22	Nonacid paste flux 4-oz. Jar	7765A14			E	McMaster Carr	3	1	1	\$3.56	\$3.56
32		32	RN55D 549K< 1%	38C8529			E	Newark	10	10	1	\$0.17	\$0.17
33		29	RN55D 931K< 1%	38C8576			E	Newark	10	10	1	\$0.10	\$0.10
34		30	RN55D 953K< 1%	38C8577			E	Newark	10	10	1	\$0.10	\$0.10
35		34	Schurter DC11	509-0001			E	Allied Electronics	10	1	1	\$6.90	\$6.90
36		38	Schurter Pushbutton	287-0019			E	Allied Electronics	10	1	1	\$18.76	\$18.76
37		25	Shrink Tube 1/4"	7496K43			E	McMaster Carr	3	1	1	\$9.86	\$9.86
38		24	Shrink Tube 3/16"	7496K42			E	McMaster Carr	3	1	1	\$7.91	\$7.91
39		26	Wire Stripper 26-16 AWG	7294K58			E	McMaster Carr	3	1	1	\$9.91	\$9.91
40		45	5/16 Captive Nut	3278			F	Warden Fluid Dynamics	9	56	1	\$0.27	\$15.12
41		46	5/16-18 SHCS 3/4"	3112			F	Warden Fluid Dynamics	9	56	1	\$0.26	\$14.56
42		47	BHCS 5/16-18x1"	91255A583			F	McMaster Carr	11	2	50	\$9.24	\$18.48
43		42	Flat Socket Head Cap Screw 8-32	91253A196			F	McMaster Carr	4	2	100	\$0.22	\$0.43
44		39	Flat Socket Head Cap Screw M6x14mm	91294A237			F	McMaster Carr	4	2	100	\$0.21	\$0.42
45		40	Socket Cap Screw 1/4-20	91255A539			F	McMaster Carr	4	1	100	\$0.14	\$0.14
46		41	Socket Cap Screw M4-16mm	91290A154			F	McMaster Carr	4	4	100	\$0.24	\$0.96
47		43	Socket Cap Screw M5-16mm	91290A232			F	McMaster Carr	4	6	100	\$0.41	\$2.48
48		44	Socket Cap Screw M5-	91294A215			F	McMaster Carr	4	4	100	\$0.59	\$2.37

			22mm										
49		48	4 Hole Angle Bracket	4303			M	Warden Fluid Dynamics	9	2	1	\$4.40	\$8.80
50		58	CCD Camera	DFK 31AF03			O	The Imaging Source	8	1	1	\$695.00	\$695.00
51		49	2.0X Auxiliary Lens	NT56-633			O	Edmund Optics	1_V2	2	1	\$135.00	\$270.00
52		51	2.0X TV Tube	NT56-626			O	Edmund Optics	1_V2	1	1	\$275.00	\$275.00
53		78	Dolan-Jenner PL-800	NT53-951			O	Edmund Optics	1	1	1	\$374.00	\$374.00
54		55	FO ADAPTER 0.629" ID	NT38-947			O	Edmund Optics	6	2	1	\$17.00	\$34.00
55		50	Focusable Lower Module	NT56-628			O	Edmund Optics	1_V2	1	1	\$248.00	\$248.00
56		56	Focusable Lower Module	NT56-628			O	Edmund Optics	7	1	1	\$248.00	\$248.00
57		52	Machine Vision Lenses	NT58-836			O	Edmund Optics	1_V2	2	1	\$30.00	\$60.00
58		54	Manual Upper Zoom Module	NT56-627			O	Edmund Optics	5_V3	1	1	\$825.00	\$825.00
59		53	Schott Combination Dual Goosenecks w/ Bundle	A08520			O	Motion Analysis Inc	2	1	1	\$185.00	\$185.00
60		57	Schott Mini Ringlights	A08670			O	Edmund Optics	7	1	1	\$227.00	\$227.00
61		59	250MM Track, 1 knob stage	NT56-798			OM	Edmunds Optics	4	1	1	\$199.00	\$199.00
62		66	Dual Coarse/Fine Movement	NT37-603			OM	Edmund Optics	6	1	1	\$185.00	\$370.00
63		61	Expanding Pin Cam Handle	CL-4-EXP-0.75			OM	Carrlane	4	1	1	\$69.50	\$69.50
64		63	Shoulder Bolt	94035A201			OM	McMaster Carr	4	2	1	\$3.74	\$7.48
65		64	Shoulder Bolt	93996A721			OM	McMaster Carr	4	2	1	\$10.82	\$21.64
66		62	Thumbscrew	99607A132			OM	McMaster Carr	4	1	1	\$1.96	\$1.96
67		67	Acrylic Plate	65754	9	12	P	XEROX FAB SHOP	X2	1	1	\$0.00	\$0.00
68		68	Steel Hold Down	65743	9	12	ST	XEROX FAB SHOP	X2	1	1	\$0.00	\$0.00
69		69	T-Slots	65657	20.5		TSLO	XEROX FAB SHOP	X1	2	1	\$0.00	\$0.00
70		71	T-Slots 1.5"	65757	6		TSLO	XEROX FAB SHOP	X2	2	1	\$0.00	\$0.00
71		70	T-Slots 3"	65756	13.5		TSLO	XEROX FAB SHOP	X2	2	1	\$0.00	\$0.00
72		77	1/4"-20 Threaded rod	98750A025			W	McMaster Carr	12	2	1	\$1.93	\$3.86
73		74	Bushing	6391K125			W	McMaster Carr	4	2	1	\$1.28	\$2.56

74		72	Metric Hex Key set	5709A45			W	McMaster Carr	3	1	1	\$20.25	\$20.25
75		73	SAE Hex Key set	5888A38			W	McMaster Carr	3	1	1	\$29.78	\$29.78
76		75	Star-Shape Knob Polypropylene	59625K71			W	McMaster Carr	12	2	1	\$0.80	\$1.60
77		76	Swivel Leveling pad	6103K24			W	McMaster Carr	12	2	1	\$5.24	\$10.48
												Total	\$4,561.56

Appendix C: Operations Manual

DODVS Operation

Note: The operation of the Drop-On-Drum Vision System can take some care and patience. Like any tool, it is imperfect, but with informed use, it can yield high quality images.

Preparation for Use

Before any images from the drum can be captured, the printer must be prepared for use. The following procedure outlines how to prepare the hardware.

1. Ensure that the optics are raised or swung out of the way.

CAUTION: Ensure the support rod is in place and properly secured or damage to the optics can occur. Refer to Optic Mounting System Use for further information.

2. Open the printer exit cover as shown in Figure C.1.

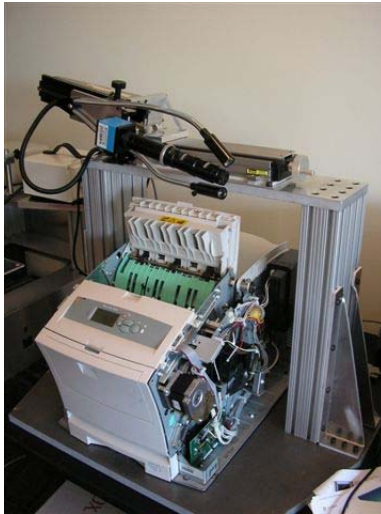


Figure C. 1: Printer with exit cover open.

3. For proper DODVS operation, the exit cover sensor must be over-ridden, so place the exit cover sensor key in the slot, as shown in Figure C.2.

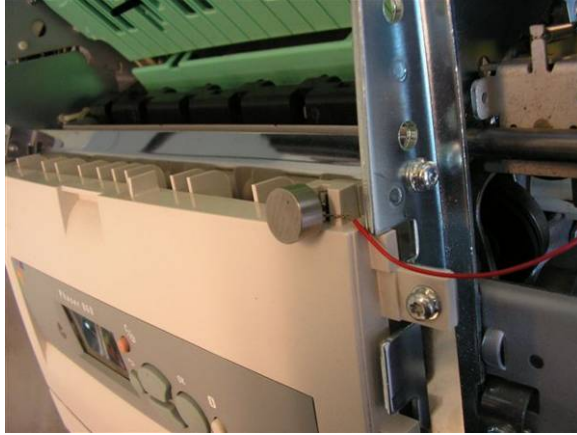


Figure C. 2: Exit cover key properly placed.

- a. Note: The key should be near or attached to the DODVS. If you can't find the key shown, anything that will trip the sensor will do. When the sensor is over-ridden, the front panel light on the printer will be lit green, not red.
4. Remove the paper track (the larger green plastic piece in Figure C.3). It's best to remove this one side at a time and yes, it does snap on and off.
5. Remove the wiper blade (the smaller green plastic piece shown in Figure C.3). This should snap off fairly easily.

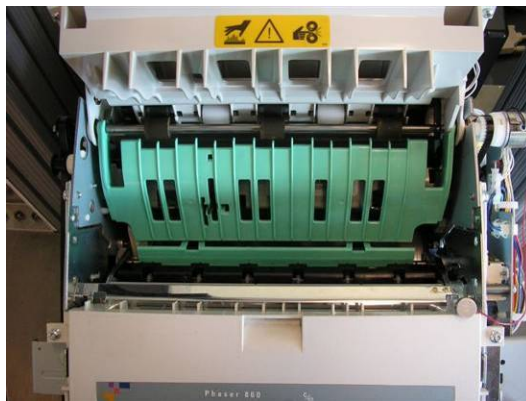


Figure C. 3: Printer with paper track and wiper in place.

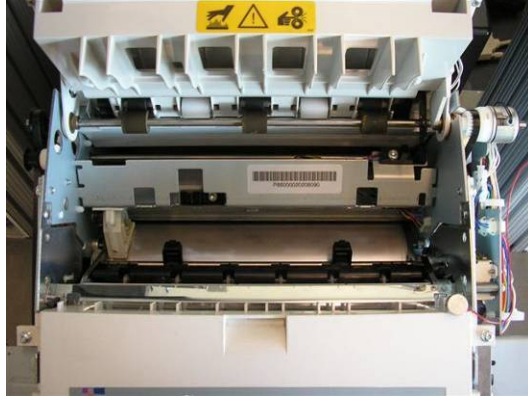


Figure C. 4: Printer with paper track and wiper removed.

Transferring Image to Drum

Before an image can be captured, the ink must be transferred to the drum and the desired image brought underneath the camera. The procedure for doing this is as follows.

1. Log on to the computer and open the Motion Console and IC Capture programs. It's useful to have both open, one on each monitor.
 - a. Note: If you are using the DODVS account on the workstation set up during this project, there should be shortcuts to both of these programs on the desktop. Otherwise, you will have to locate, install and/or configure these programs, which can be a tricky process.
 - b. Note: You may have to enter the IP address of the printer when opening the Motion Console. If so, it is located in the ip_address.txt file on the desktop of the DODVS account.
2. Ensure that the Motion Console loaded correctly by checking that the stage controller and printer connection status indicators are green. If not, you'll need to get software help. The proper program window is shown in. Figure C 5.

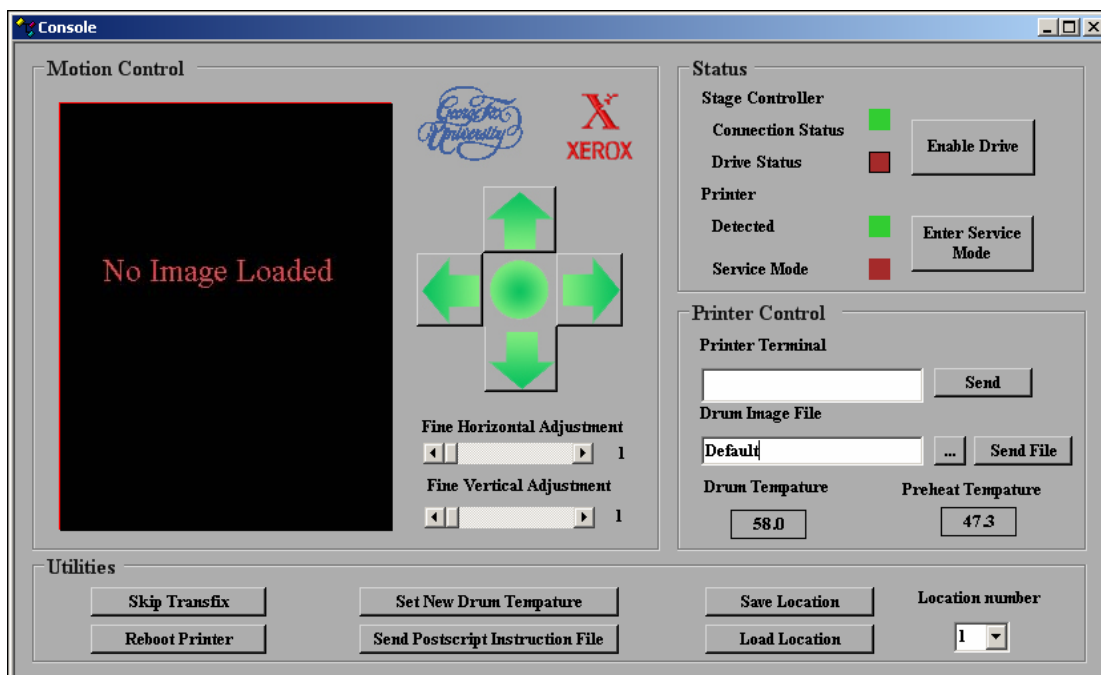


Figure C. 5: Motion Console program window when first loaded.

3. Send an image to the printer drum by clicking the button with an ellipsis (...) under the Drum Image File label. Locate the desired Postscript file and press OK. The image should appear in the program window.
 - a. Note: The image that appears may be a default image. We tried to fix this, but time was limited.
4. Press the “Send File” button next to the file name and the image will be transferred onto the drum.
 - a. Note: Sometimes the printer needs to warm up before the image can be transferred. With the exit cover open to take pictures, this can take a long time. Just be patient. When the drum temperature and preheat temperature are in the 60 degree range, and the message on the printer front panel display says “Ready to print” rather than “Warming up”, the printer should be ready.
5. Check the IC Capture program window (or just look at the printer drum) to ensure that the image has indeed been transferred. When the image is on the drum of the printer, the desired portion of the drum can be located and brought into focus.

Locating the Desired Area

Before continuing, make sure that the lens assembly and the goosenecks are out of the way of the printer.

1. In the Motion Console program, press the “Enable Drive” and “Enter Service Mode” button to enable motion control of the drive and the stage. The stage will home out to its leftmost position. When both are complete, the “Drive Status” and “Service Mode” indicators should both be green.
2. Use the crosshairs in the Motion Console program window to position the optics near the center of the drum.
3. Swing the optics into the vertical position and use the long-travel stage to lower the assembly near the printer drum. The maximum working distance is 32 mm (about 1.25 inches), so the end of the lens assembly should be at most that far from the drum. The entire DODVS with the optics in working position are shown in Figure C.6.



Figure C. 6: DODVS with optics in working position.

4. Adjust the lighting goosenecks so that the area directly under the lens is illuminated. The intensity of the light from the supply can also be adjusted, but the maximum seems to usually work well.
5. Focus the camera on the current portion of the drum.
 - a. Adjust the coarse-adjust knob of the optics mount to bring the image in the IC Capture window nearly into focus.
 - b. Adjust the magnification to the desired level using the upper dial on the lens assembly.
 - c. Use the fine-adjust knob on the optics mount to bring the area fully into focus. The focus on the lens assembly (the lower dial) can also be used, but the fine-adjust knob seems more sensitive and is more accessible.
6. Use the cross-hairs on the image in the program window to move the drum and stage to the approximate location of the desired image.
 - a. Note: These cross-hairs may not work quite right. We tried to fix it, but time was limited and the position along the drum axis may still have problems. Either try to deal with it or find someone knowledgeable to modify the software.
7. Use the arrows and the fine-adjust sliders to more precisely locate the desired position on the image. If you disable the drive, you can also use the hand crank

on the end of the stage to move it into position, and manually turn the drum to get it into the right position. Unfortunately, at this point manual adjustment often is more precise than the automated movement.

8. Re-adjust the goosenecks and re-focus the optics if necessary to obtain the best lighting and image quality.

Capturing Image and Transfixing to Paper

1. The IC Capture program is used to capture images. To freeze the display at the current image, select “Snap Image” from the “Capture” menu and to save an image to disk, select “Save Image” from the “Capture” menu.
2. If multiple images from the same page are desired, relocate the drum and stage to the proper position using the steps outlined above, and capture them in the same manner.
3. When all images have been taken, the page can be printed for comparison using the BTM. To do this, the printer must be restored to a normal working state.
 - a. Move the optics out of the printer using the long-travel stage and the tilt feature of the optics mount.
 - b. Re-install the wiper blade and paper track, in that order.
 - c. Remove the exit cover key and close the exit cover.
 - d. Press the “Exit Service Mode” button in the Motion Console program to take the printer out of service mode. The page should now print out normally and can be used with BTM for further analysis.

Optic Mounting System Use

1. To move the optic system out of the printer
 - a. Move assembly to the left side of the printer
 - b. Release and remove the expanding pin cam located on top of the assembly, figure C.7, by lifting up
 - c. Carefully swing the assembly up to the left
 - d. Put the support rod in place and ensure the thumbscrew is securely fastened, figure C.8.

CAUTION: If the support rod is properly installed and the thumbscrew securely fastened damage to the optics can occur.

2. To move the lens assembly into the printer reverse a-d

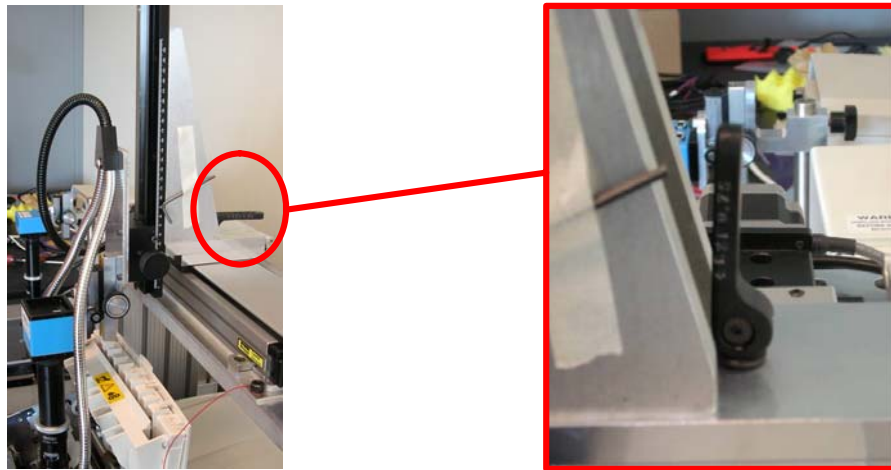


Figure C. 7: Expanding Pin Cam moved to the released position

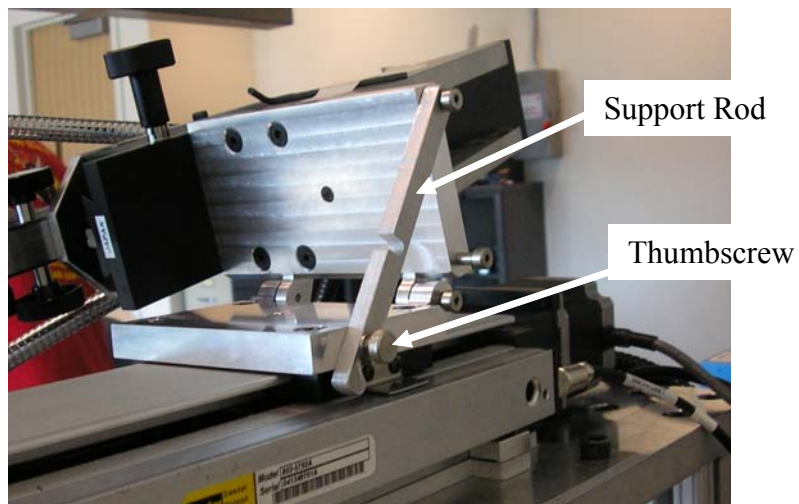


Figure C. 8: Rear view of the DODVS optic mount in the open position showing the support rod and thumbscrew properly in place

BTM Operation

1. Located the two orange RJ-45 ports, one on the right side of the BTM and one on the joystick.
2. Connect a STRAIGHT through CAT 5 cable.

NOTE: CAT 6 cable can be used as long as it is not crossover.



Figure C. 9: **Connect a CAT 5 cable to the two orange RJ-45 ports.**

3. Press the power button on the joystick to turn on system.
4. To operate the stage, press and hold the button at the top of the joystick while operating it. If button is not pressed moving the joystick the stage will not operate.
5. Once you are done using the BTM press the power button again to shutoff.

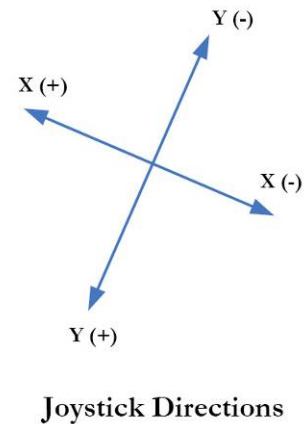
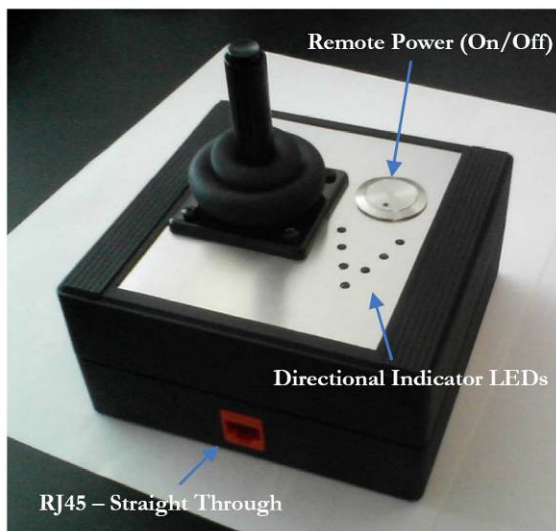


Figure C. 10: **Joystick controls. The speed of the stage is dependent on the degree of motion on the joystick.**

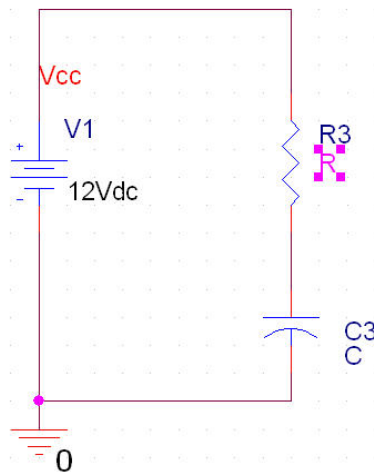
Appendix D: Calculations

BTM Power-On Delay

Summary

The purpose of this analysis is to eliminate the “bounced” signal when pressing power button. Unlike a latching pushbutton a momentary push button has ripple when pressed. Instead of a single pulse going to “set” on a relay along the system to stay on, the ripple creates multiple pulses that causes it to set and reset making the system turn on a off based on one push. For the delay we want to have from 2 to 5 second delay before enabling the shutoff function.

Schematic



Given

$$T_{sec} = 1.1 \times R \times C$$

$$R = 10K \Omega$$

$$C = 235 \mu F$$

Solution

$$T_{sec} = 2.585 \text{ sec}$$

DODVS Frame Vibrations

Summary

The purpose of this analysis is to determine the deflection and natural frequency of the DODVS side supports. The natural frequency and deflection of the supports play pivotal roles in overall image quality. In determining the optimum frame design for the DODVS and BTM, an analysis of several designs was performed in ANSYS. This appendix contains an abridged version of the analysis performed on the frame designs; there were a total of 14 combinations analyzed. This document covers the final design that was chosen. Knowing the general shape of the system, finite models were created representing the worst-case-scenario of a solid aluminum frame, not one constructed of TSLOTS. The TSLOTS material has a high stiffness due to the stress concentrations in material of the internal, extruded design. For this analysis ANSYS 10.0 will be used.

Schematic

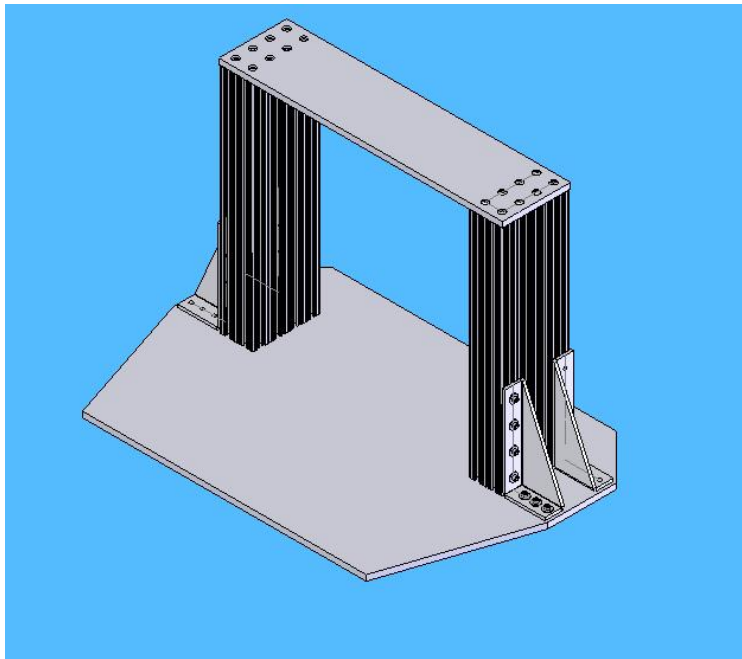


Figure A. 1: 6"x3" TSLOTS with 1/4" gussets.

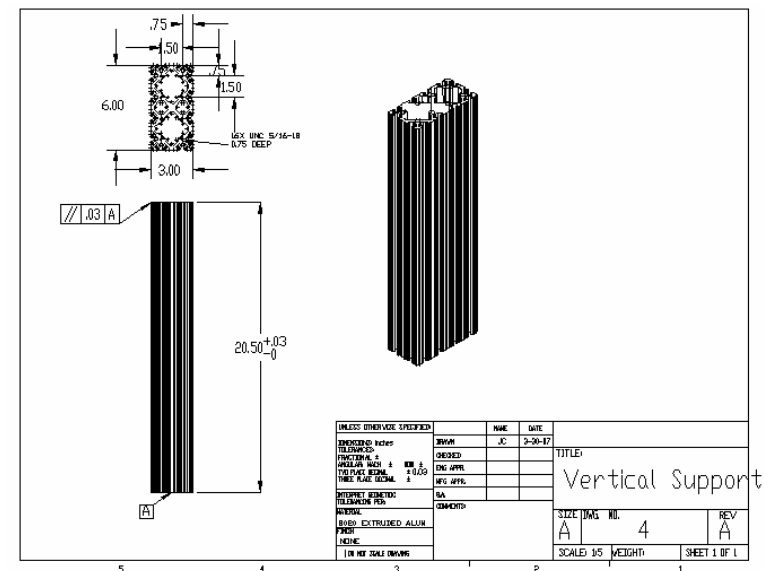


Figure A. 2: Schematic of side support.

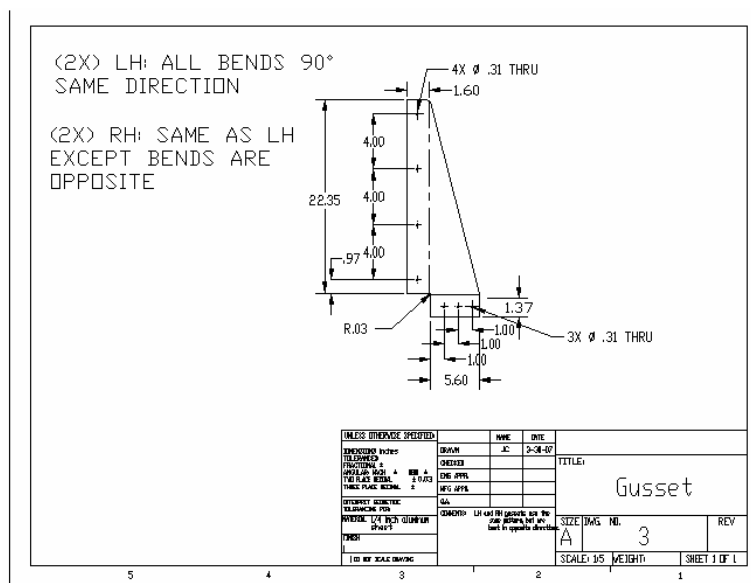


Figure A. 3: Schematic of gusset used in side support.

Given

- An applied load of 10 N.
- TSLOTS material: 6061 Al, $E = 60.9 \text{ GPa}$.
- $\rho = 2800 \text{ kg/m}^3$
- Component dimensions as given in schematics.
- Support and gusset are fixed at base plate.
- Force is applied in one direction only.

Find

- The theoretical natural frequency of the system
- The deflection of the system

Assumptions

- This is a worst case scenario, meaning the support will be evaluated as a solid, not the much stiffer honeycomb aluminum the TSLOTS actually is.
- The system will be tested as an undamped oscillating system and as a damped system.

Solution

A solid model was imported into ANSYS via the *Import* function. Using the model, which containing the geometric properties desired (area, moment of inertia, etc.), the model was designated a solid tetragonal node (Solid # 187) with a known density. The loads were then applied, being fixed on one end with a 10 N load anti-parallel to the X-axis. The mesh was created using the free mesh tool for a volume.

The solution was completed using the TIMEHIST POSTPROC function, with 100 different frequencies analyzed. Figure A.4 is the data obtained from ANSYS.

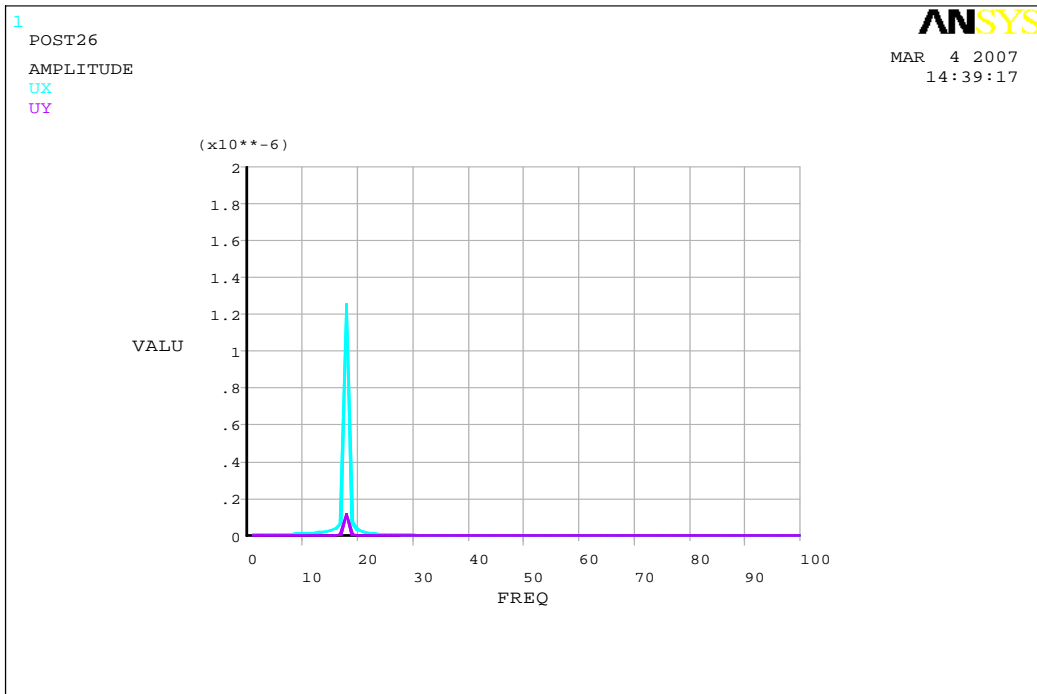


Figure A. 4: Frequency analysis of DODVS frame.

This shows a theoretical natural frequency of 18 Hz, 6 Hz higher than the previous model (for information on the original frame, see appendix E). Also, the response of the system is near zero for all other frequencies other than near $r = 1$.

With this configuration, the natural frequency of the system was moved to 18 hertz and the amplitude of oscillation was decreased. Since this is a worst case scenario, the amplitudes for un-damped system are:

Axis	Amplitude (+,m)	Amplitude (-,m)
UX	2.11E-06	-1.26E-06
UY	1.15E-07	-1.23E-06

For a damped system the amplitudes become:

	Amplitude (+,m)	Amplitude (-,m)
UX	2.25E-08	-2.34E-08
UY	2.20E-09	-1.98E-09

In either case, the amplitudes are well below the dimensions of our viewing range set in the PDS, which is 42.3 μm (or 1/600"). The design shown in figure A.4 (in a worst case

scenario) has a natural frequency 8 Hz higher than the current DODVS and the amplitude of oscillation has decreased from 533 μm to 2.11 μm .

Summary

The experiment in Appendix X was inconclusive because the rigidity of the system prevented it from setting into a clean oscillation that the strain gage could detect. To put it more accurately, a load could not be appropriately applied to give the desired results. During the experiment, this calculation was performed to determine how large of a load would need to be applied to get a change of 1 mV from the bridge circuit.

Load required for adequate change in voltage

Schematic

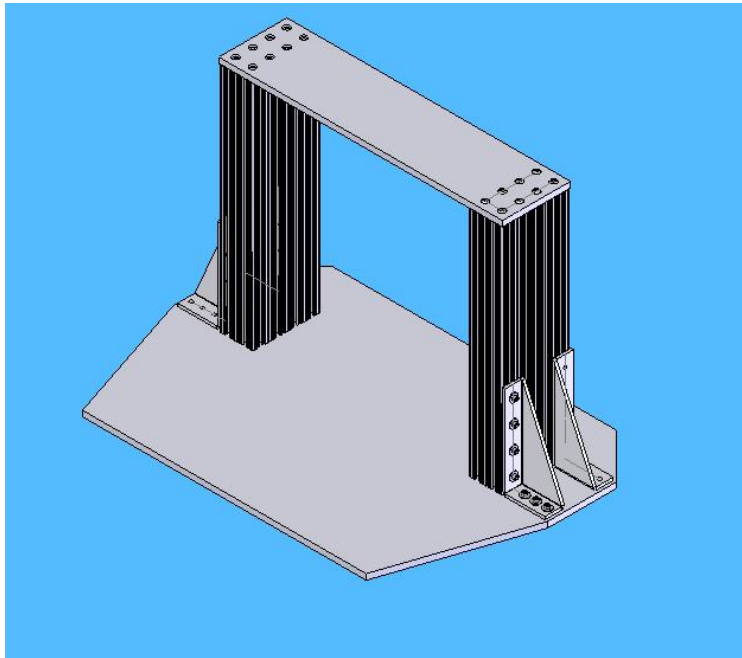


Figure A. 5: Due to the size and shape of the system, setting it into oscillation was difficult.

Given

- $GF = 2.100$ Gage factor
- $E = 1000 \text{ KSI}$ Young's modulus
- $L = 20.5 \text{ in}$ Length

- $V_{ex} = 12 \text{ V}$ Excitation voltage
- $I = 6.4300 \text{ in}^4$ Moment of inertia
- $V_O = 0.2900 \text{ V}$ Average output voltage

Assumptions

To find the applied load to get a change in V_O of 1 mV, in the calculation, V_O will be 0.291 V.

Find

The applied load necessary to get a change in voltage of 1 mV.

Solution

$$\sigma = \varepsilon E = \frac{P \cdot L \cdot c}{I}$$

$$\varepsilon = \frac{P \cdot L \cdot c}{I \cdot E}$$

$$\frac{V_O}{V_{ex}} = \frac{A \cdot GF \cdot \varepsilon}{4}$$

$$V_O = \frac{V_{ex} \cdot A \cdot GF \cdot \varepsilon}{4}$$

$$P = \frac{I \cdot E \cdot 4 \cdot V_O}{V_{ex} \cdot A \cdot GF \cdot L \cdot c} = \frac{(6.43 \text{ in}^4)(1000 \text{ KSI})(4)(0.29 \text{ V})}{(12 \text{ V})(100)(2.1)(20.5 \text{ in})(1.5 \text{ in})} = \mathbf{96.58 \text{ lbf}}$$

Optics Calculations

Summary

The purpose of this analysis is to determine how the previous optical system affected the quality of the images produced by the DODVS, and what improvements are attained by the current optical components. The effects of the camera and lens assembly on resolution and field-of-view are determined and compared to the relevant design requirements, namely imaging areas of 1/600" to 40/600" and image distortion as low as possible.

Given

- Old Thales-Optem Zoom 70XL lens assembly configured with a standard 1X-7X variable zoom module, a 2X mini TV tube, and no auxiliary lenses. This results in the following optical properties:
 - NA = 0.024 to 0.080 (variable) Numerical aperture
 - FOV = 3.2 mm to 0.45 mm (variable) Horizontal field-of-view
- Current Thales-Optem Zoom 70XL lens assembly configured with a standard 1X-7X variable zoom module, a 2X mini TV tube, and a 2X auxiliary lens. This results in the following optical properties:
 - NA = 0.048 to 0.16 (variable) Numerical aperture
 - FOV = 1.6 mm to 0.22 mm (variable) Horizontal field-of-view
- Imaging Source DFK 31F03 1/3" CCD camera, with the following properties:
 - $L_{\text{pixel}} = 4.65 \mu\text{m}$ Pixel side length
 - $L_{\text{sensor}} = 4.8 \text{ mm}$ Horizontal sensor side length

Find

The magnifications, imaging areas and minimum resolvable distances offered by the two systems.

Solution

The overall magnification for the system (primary magnification) can be found from the formula given in [1].

$$\text{PMAG} = \frac{L_{\text{sensor}}}{\text{FOV}}$$

For the old lens assembly, this results in:

$$\text{PMAG}_{\text{min}} = \frac{L_{\text{sensor}}}{\text{FOV}_{\text{max}}} = \frac{4.8 \text{ mm}}{3.2 \text{ mm}} = \mathbf{1.5}$$

$$\text{PMAG}_{\text{max}} = \frac{L_{\text{sensor}}}{\text{FOV}_{\text{min}}} = \frac{4.8 \text{ mm}}{0.45 \text{ mm}} = \mathbf{10.7}$$

For the current lens assembly, this results in:

$$\text{PMAG}_{\text{min}} = \frac{L_{\text{sensor}}}{\text{FOV}_{\text{max}}} = \frac{4.8 \text{ mm}}{1.6 \text{ mm}} = \mathbf{3.0}$$

$$\text{PMAG}_{\max} = \frac{L_{\text{sensor}}}{\text{FOV}_{\min}} = \frac{4.8 \text{ mm}}{0.22 \text{ mm}} = \mathbf{21.8}$$

The imaging areas are actually just the horizontal field of view. These and the requirement are converted to the same units for clarity and listed together for comparison.

Requirement:	1.69 mm (max) to 0.042 mm (min)
Old system:	3.20 mm (max) to 0.450 mm (min)
Current system:	1.60 mm (max) to 0.220 mm (min)

The minimum distance between points resolvable by the system depends on both the optical and the digital resolution. The minimum resolvable distance for the lens assembly is given by the equation from [2].

$$h_{\min} = \frac{0.61\lambda}{\text{NA}}, \text{ where } \lambda \text{ is the wavelength of the light passing through the system.}$$

The optical spectrum is from 400 nm to 700 nm, so at minimum magnification, the old system can resolve points separated by:

$$h_{\min} = \frac{0.61 \cdot 400 \text{ nm}}{0.024} = 10 \mu\text{m} \text{ to } h_{\min} = \frac{0.61 \cdot 700 \text{ nm}}{0.024} = 18 \mu\text{m}$$

At maximum magnification, the resolvable distances are:

$$h_{\min} = \frac{0.61 \cdot 400 \text{ nm}}{0.080} = 3.0 \mu\text{m} \text{ to } h_{\min} = \frac{0.61 \cdot 700 \text{ nm}}{0.080} = 5.3 \mu\text{m}$$

The minimum resolvable distances for the new system can be calculated in the same way.

At minimum magnification, they are:

$$h_{\min} = \frac{0.61 \cdot 400 \text{ nm}}{0.048} = 5.1 \mu\text{m} \text{ to } h_{\min} = \frac{0.61 \cdot 700 \text{ nm}}{0.048} = 8.9 \mu\text{m}$$

At maximum magnification, the resolvable distances are:

$$h_{\min} = \frac{0.61 \cdot 400 \text{ nm}}{0.16} = 1.5 \mu\text{m} \text{ to } h_{\min} = \frac{0.61 \cdot 700 \text{ nm}}{0.16} = 2.7 \mu\text{m}$$

To determine exactly what the minimum resolvable distance is, the digital limit due to the finite number of pixels in the camera must also be determined. This is known as the object resolution and is given by a formula from [1].

$$\text{RES}_{\text{OBJ}} = \frac{2 \cdot L_{\text{pixel}}}{\text{PMAG}}$$

This will also result in a range due to the variable magnification. For the old system:

$$RES_{OBJmax} = \frac{2 \cdot L_{pixel}}{PMAG_{min}} = \frac{2 \cdot 4.65 \mu m}{1.5} = 6.2 \mu m$$

$$RES_{OBJmin} = \frac{2 \cdot L_{pixel}}{PMAG_{max}} = \frac{2 \cdot 4.65 \mu m}{10.7} = 0.87 \mu m$$

For the new system, the resolution range is:

$$RES_{OBJmax} = \frac{2 \cdot L_{pixel}}{PMAG_{min}} = \frac{2 \cdot 4.65 \mu m}{3.0} = 3.1 \mu m$$

$$RES_{OBJmin} = \frac{2 \cdot L_{pixel}}{PMAG_{max}} = \frac{2 \cdot 4.65 \mu m}{21.8} = 0.43 \mu m$$

For each system, the actual minimum resolvable distance is the maximum of the optical and digital resolution values. The results for both systems are listed below.

Old system: **18 μm** (max) to **5.3 μm** (min)

Current system: **8.9 μm** (max) to **2.7 μm** (min)

References

[1] Edmund Optics, Inc. *Electronic Imaging Resource Guide*.

<http://www.edmundoptics.com/techSupport/DisplayArticle.cfm?articleid=286>

[2] Francis T. S. Yu and Xiangyang Yang. *Introduction to Optical Engineering*.

Cambridge University Press, 1997.

Appendix E.1: Experimentation

Vibration analysis of the original DODVS

Objective

The objective of this experiment was to mount strain gages onto the surface of the original DODVS and observe its damped frequency after it has been set into oscillation. A Virtual Instrument (VI) has been created in LabView and the VI interprets the output voltage from the bridge circuit, to which the strain gages will be connected, as the vibration of the system. This was done by putting the data into a Fast Fourier Transform (FFT). The FFT graph created in LabView shows all frequencies affecting the system;

knowing all frequencies affecting the system allowed the capstone design team to insure that vibration modes of the new system will be designed away from these frequencies.

To validate the data obtained by LabView, the natural frequencies determined experimentally were compared to a theoretical solution. Due to the complex shape of the DODVS, a Fine Element Analysis (FEA) was performed using ANSYS to determine the natural frequency. In the end, the observed and theoretical values will be used to calculate the damping coefficient of the DODVS.

Theory

The tool used for this experiment is a strain gage. Strain gages work in the following way: they have a nominal resistance (determined by the type of wire they are composed of and its length), when the gage is adhered to the surface of the system in question, it will deform with the outermost fiber of the material. Depending on whether the surface is in tension or compression, the resistance of the gage will change by increasing or decreasing. When the gage is connected as the fourth resistor in a bridge circuit (Figure E.1), the change in resistance of the gage will correspondingly create a change in the output voltage, which related to the strain by:

$$\varepsilon = \frac{4V_o}{V_{ex} \cdot A \cdot GF}, \text{ where } V_o = \text{Output voltage, } V_{ex} = \text{Input voltage, GF} = \text{Gage factor and}$$

A = Amplifier gain.

When the strain gages are attached to the surface of a system that has been set into oscillation, the gage will cycle through compressive and tensile forces. This constant change in voltage output from the bridge circuit can be interpreted as the frequency of the system by the FFT.

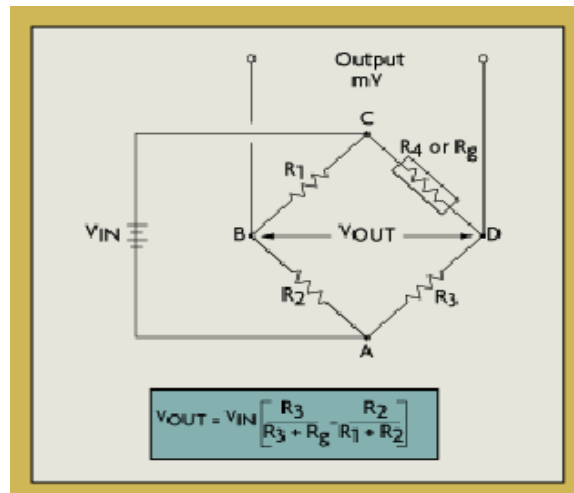


Figure E.1. 1: A Wheatstone bridge circuit. For this experiment R4 will be the strain gages used and all resistances are nominally 120 Ω.

Method

For this experiment a VI was written in LabView that would collect the voltage signal from the bridge circuit and display the data in the form of an FFT and a direct measure of the voltage in real-time. After setting up the VI, the next steps were applying the strain gages, making sure they were functioning properly and resolving any issues that were hindering the quality of the data. Four strain gages were placed on the DODVS frame: two on the right support panel, one on the center connection bracket and the last one on the right panel ground support.

PART NAME: XXX_BASE_TILT_RIGHT

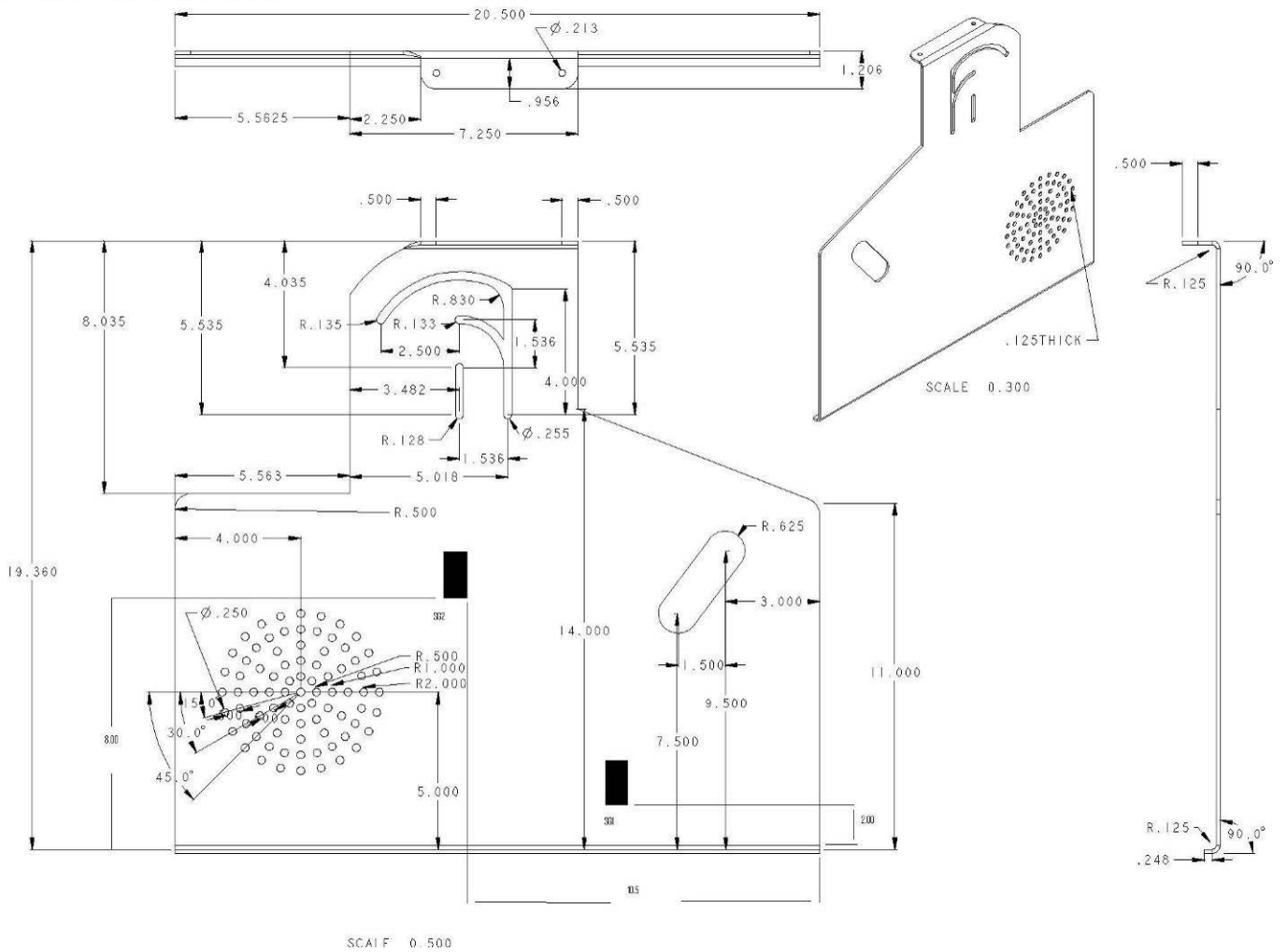


Figure E.1.2: Schematic of the DODVS right panel featuring the locations of strain gages one and two.

The strain gages were applied by first selecting locations that would best sense the strain in the system:

- Strain gage one (SG1) was placed two inches from the base of the frame on the support rail that was tack-welded to the frame.
- Strain gage two (SG2) was placed on the right panel in a place where it wasn't near an area that was affected by stress concentrations.
- Strain gage three (SG3) was placed on the center support bracket in an effort to prove that both frame panels oscillated at the same frequency (Figure 3). If the strain gage detected no load, it meant that the gage was accelerating at the same rate as both of the panels. If the acceleration of the two panels were the same (no net force), then there was no tensile or compressive forces on the panel, meaning the gage wouldn't have a change in resistance and thus no change in output voltage.

- Strain gage four (SG4) was placed on the right panel ground support (Figure 3). Since the support is connected to the oscillating frame and the base plate, it would experience tensile and compressive forces as the panel oscillated. The frequency of the tensile-compressive cycle would be equivalent to the natural frequency of the panel.

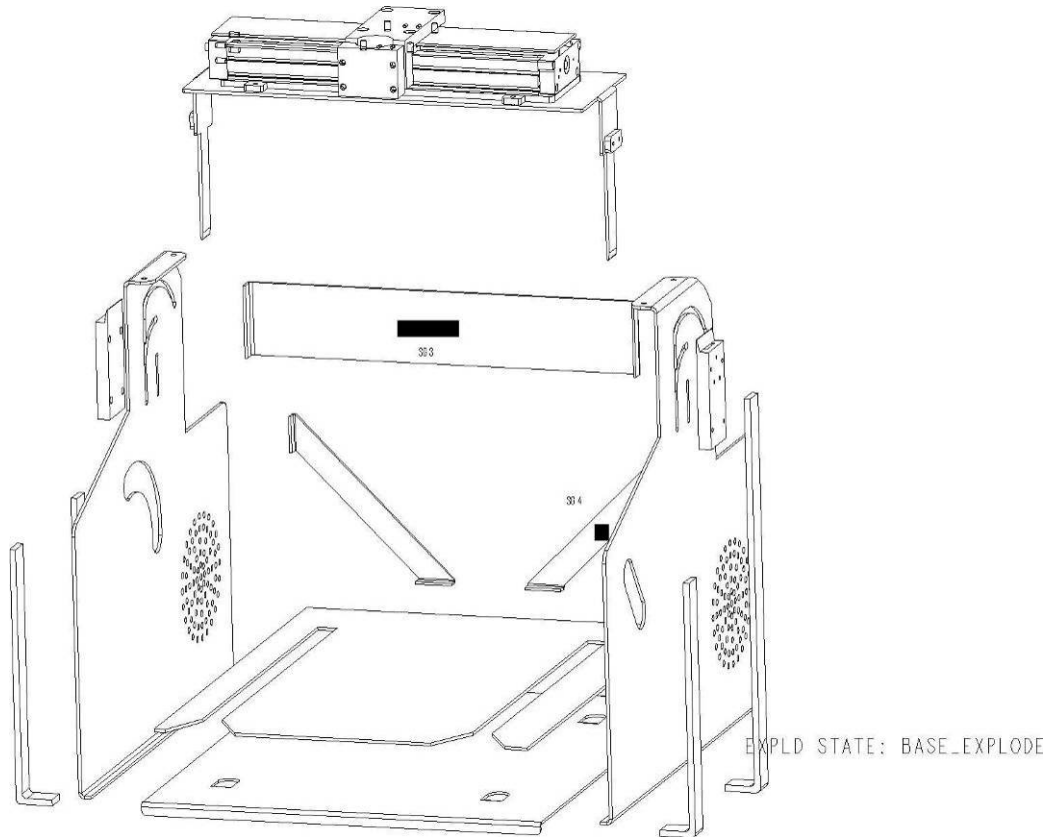


Figure E.1. 3: Exploded view of DODVS with locations of SG3 & SG4 indicated.

With the locations of strain gages determined, the next step was to apply them: the first step was to sand the location where the gage was to be placed with 220 grit sandpaper. Following that, the surface was wet-sanded with 320 grit sandpaper and degreaser, followed by wiping the surface down with degreaser. The surface was then prepped with conditioner and a neutralizer. The strain gage was then picked up with four inches of cellophane tape (terminal side up) and placed along scribe marks laid down to indicate its final position. With the tape folded back, a solution of isopropyl alcohol was applied to surface of the gage and it was allowed to dry. The gage was then glued to the surface and held in place for three minutes with significant pressure from the installers thumb. Once the glue had dried the lead wires were soldered into place and tested by checking the resistance of the gage. The gage application process was identical for all four gages.

With the gages setup, the bridge circuit was created on the Proto-board and the output voltage was run through an amplifier circuit with the gain set to 100. The output voltage from the amplifier was then input into the Data Acquisition card (DAQ) and LabView collected the data. A photograph of the setup for this experiment can be seen in figure six.

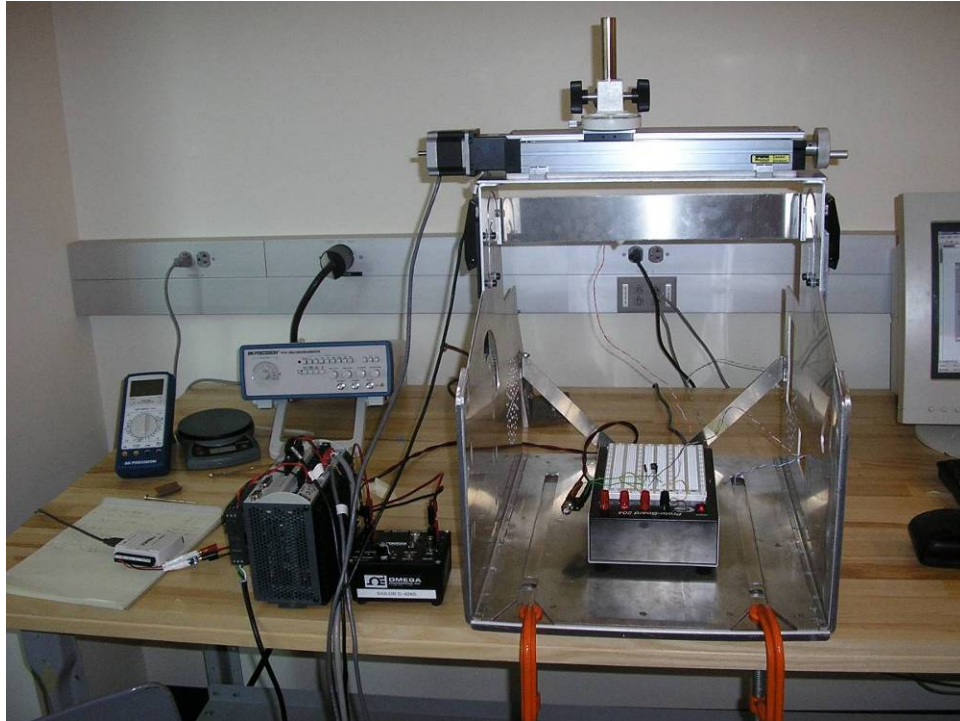


Figure E.14: Configuration of the apparatuses used for this experiment.

Data Collection

Once the system had been setup, as seen in figure six, the data collection process was started. For this experiment, there was no need to calibrate the gages because the only data that mattered was the damped frequency, which was determined by the Fast Fourier transform. To determine the damped frequency, the system was set into oscillation by moving the camera mount. The camera mount was moved by turning the handle on the translation stage one-half of a turn, which caused the mount to move and the force caused a deflection that set the system into oscillation. For strain gages 1, 2 and 4 this procedure was replicated three times to validate the data. For strain gage three, the assumption made about the system (pp. 5) held true and the resulting output from the FFT in LabView showed only the ubiquitous 60 Hz frequency of nearby objects running on AC current. It was decided that it was important to know the individual frequency of the centre mount bracket; to determine this frequency, the bracket was “plucked” and set into oscillation. This was replicated three times to validate the data.

Analysis

The analysis of the experiment was performed by examining the output of the FFT graph on the VI front panel. At the beginning of the experiment the graphs were giving false data: showing a frequency of 1 Hz and noise of large amplitude throughout the entire spectrum in question; this type of noise was occurring on all four strain gages, indicating that there was something wrong with the setup. Knowing the frequency displayed by the FFT had to be incorrect because, visually, one could tell that the natural frequency was at least 5 Hz, if not higher. This prompted a tear down of the setup to try and find any sources of error. In this case there were two faulty hookups and a power cord lying directly across the bridge circuit. Once the connections were fixed and all power cords were moved away from the setup, proper data was obtained.

Once all problems had been sorted out, various sampling rates were tried to best optimize the peak voltage of the FFT graph. When the sampling rate was too low, the peak voltage on the FFT covered too broad of a spectrum: it was hard to tell if the measured frequency was 9 or 10 Hz. Sampling rates of 500, 1000, 2000, 5000 and finally 10,000 samples per second were tried; 10,000 being the most samples LabView would allow. When the frequency was in the range of 10 KHz, the peak of the graphs was distinguishable; however, due to the density of data being displayed there was significant noise across the spectrum of frequencies tested. This displayed noise was acceptable in the end because the peaks of the frequencies measured were clear and distinct.

The data obtained from the experiment was compared to the results obtained from an ANSYS analysis of the system. The natural frequency calculated using ANSYS will be considered the theoretical frequency and the frequency obtained experimentally will be considered the damped frequency of the system.

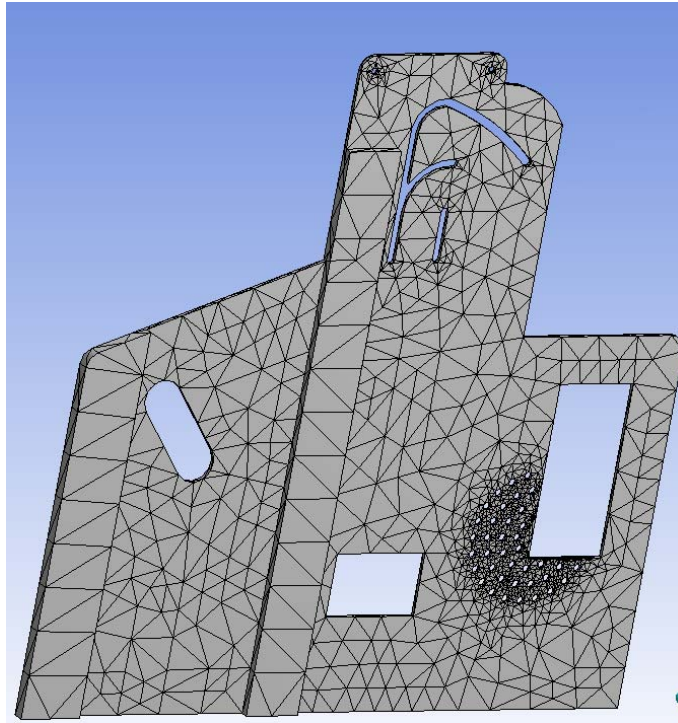


Figure E.1.5: Fully meshed, Finite Element Analysis model of the right support panel of the DODVS. The theoretical natural frequency of the system is 12.86 Hz.

The damping coefficient of the system (ζ) can be determined from equation two.

$$\omega_d = \omega_n \sqrt{1 - \zeta^2} \quad (2)$$

The testing of the system showed a damped frequency 10 Hz and the theoretical natural frequency of the system determined in ANSYS was 12.86 Hz. Knowing these two values, the damping coefficient of the system can be determined.

$$\begin{aligned} \omega_d &= \omega_n \sqrt{1 - \zeta^2} \\ \zeta &= \sqrt{1 - \left(\frac{\omega_d}{\omega_n}\right)^2} \\ \zeta &= \sqrt{1 - \left(\frac{10}{12.86}\right)^2} \\ \zeta &= 0.629 \end{aligned} \quad (2.1)$$

When this experiment was performed, there was an attempt to collect the change in output voltage versus time using LabView and use that data to determine the damping coefficient; however, the system damped too quickly for LabView to accurately display change in output voltage as time changed. Knowing the damping coefficient calculated above, LabView's inability to collect proper data because the system damped too quickly makes sense; going into this experiment, the anticipated damping coefficient was 0.1-0.25.

Results and Discussions

The data collected in the lab was a FFT of the output voltage from a bridge circuit, where the fourth resistor was as strain gage attached to an oscillating system. The following figures are representative graphs of the damped frequency of the system. Only one graph per strain gage will be shown in this section, all other FFT graphs can be seen in Appendix C.

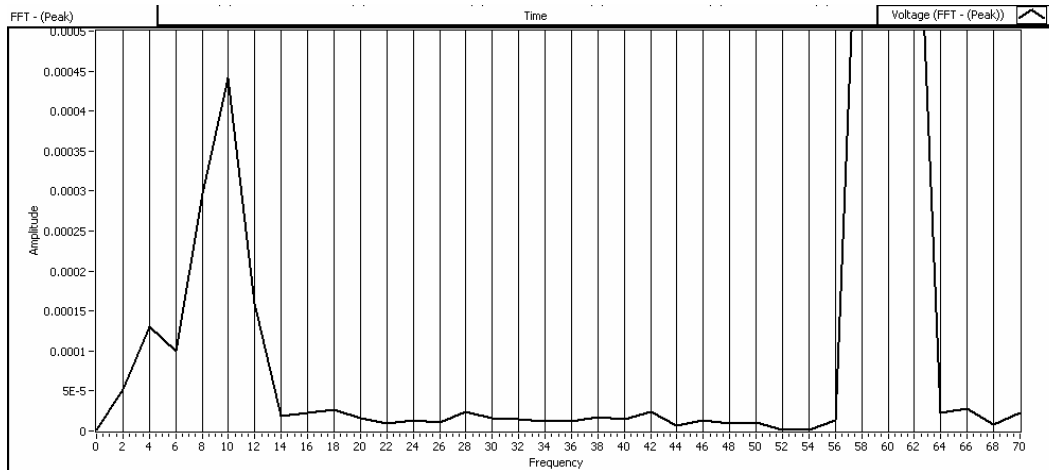


Figure E.1.6: Damped frequency of system as determined by SG1

The output from SG1 shows a natural frequency of 10 Hz; there is also a detected frequency at 60 Hz. This detected frequency is that of objects on the table being powered by 120 VAC-60 Hz current, like the computer monitor and the Proto-board. There is also a noticeable response at 4 Hz that was present in all three trials with SG1 and on one trial from SG2 and SG3.

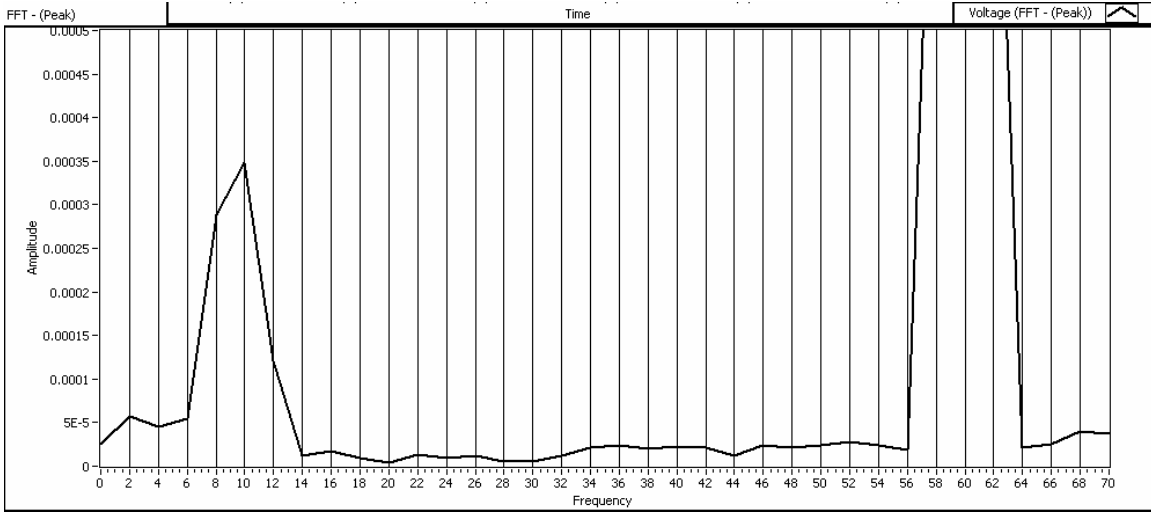


Figure E.1. 7: Damped frequency of system as determined by SG2

Figure 9 shows the damped frequency which was detected by SG2, which was also mounted directly to the right support panel. This figure shows the damped frequency and the ubiquitous 60 Hz frequency. It also shows there is very little response between 14 and 56 Hz, meaning the system would operate well within this range.

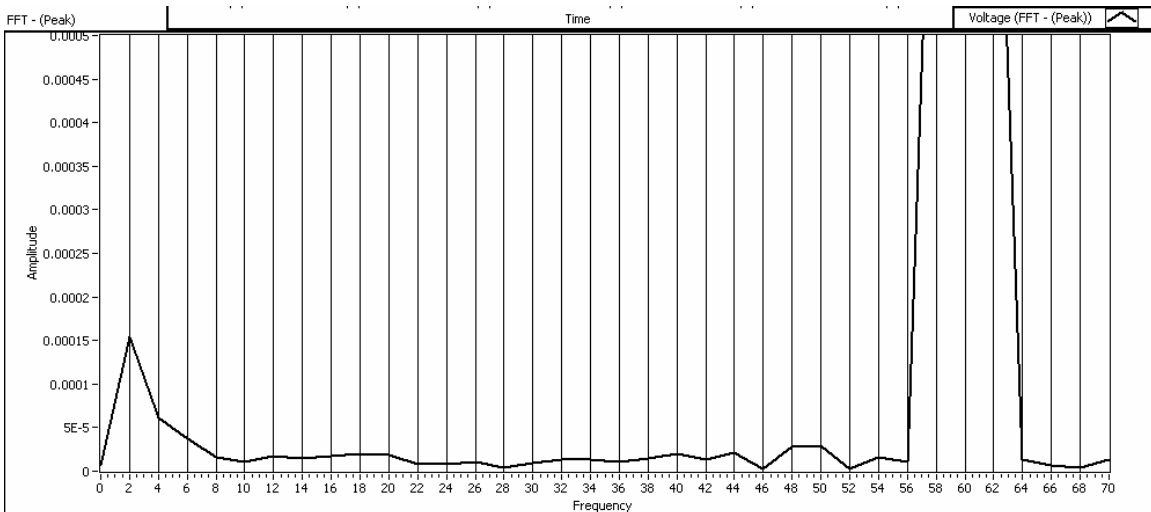


Figure E.1. 8: Frequency of the centre support bracket when applied load vector is perpendicular to the force vector applied by the linear translation stage.

As stated above in the methods section of the document, the behavior of SG3 satisfied the hypothesis established before the experiment was conducted: both support panels oscillate at the same frequency, meaning there is zero net force on the centre bracket because both ends of the bracket are accelerating at the same frequency. Because this hypothesis was satisfied, the individual damped frequency of this component was determined by “plucking” the bracket with a force vector perpendicular to the force vectors that were used to excite the right support panel. The damped frequency of this component turned out to be 2 Hz.

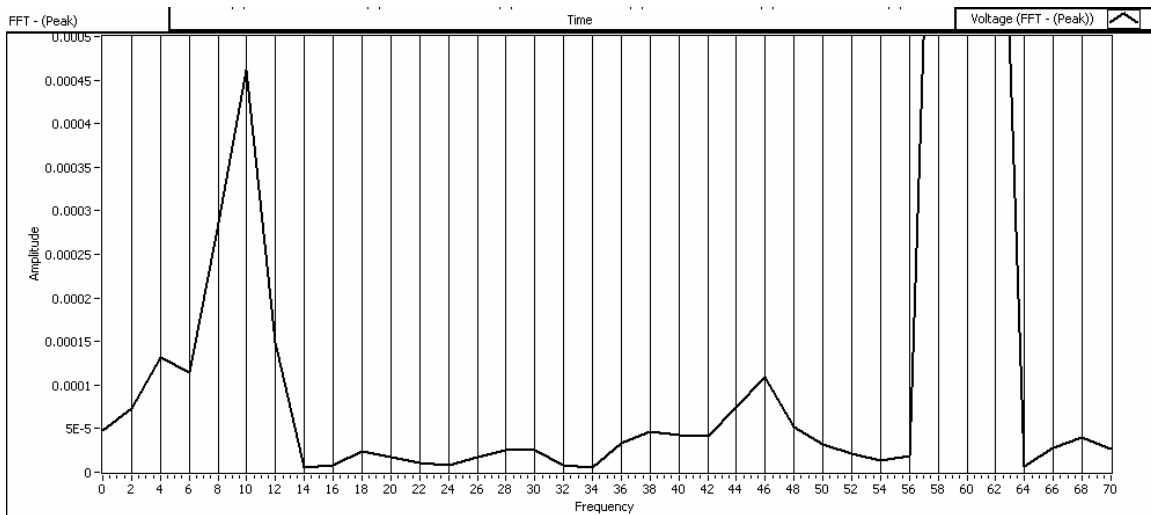


Figure E.1.9: Damped frequency of system as determined by SG4

SG4, which was mounted on the right panel ground support, detected a system damped frequency of 10 Hz, like SG1 and SG2, as predicted in the methods section of this document.

Discussions

By mounting four different strain gages on a DODVS frame, the damped frequency of the system was determined and the damping coefficient was determined by knowing: the theoretical natural frequency predicted by ANSYS, the observed damped frequency and equation 2.1. The three strain gages designated to determine the damped frequency of the system detected identical frequencies: a damped frequency at 10 Hz and an AC current induced 60 Hz frequency. Five of the twelve trials also detected a 4 Hz frequency. This frequency occurring in five out of twelve trials indicates that something within the Engineering Building was turned on and off throughout the experiment: like

the elevator. It may also be the natural frequency of the third floor of the building; it may have only been detected five times because the amplitude of the oscillation was changing with time. The strain gage mounted on the centre support bracket proved the hypothesis that both the right and left support panels oscillated at the same frequency. With that crucial hypothesis verified, the damped frequency of the bracket was determined. Knowing the frequency of this component, it would allow the PSU capstone team to know at which frequencies the system was activated and be able to use this data to evaluate picture quality when the new DODVS is built in April 2007. As seen in figure ten, the damped frequency of the bracket is 2 Hz.

Uncertainty Analysis

Resolution of $\omega_d = \pm 0.4$ Hz, $U\omega_d = \pm 0.2$ Hz

Resolution of $\omega_n = \pm 0.01$ Hz, $U\omega_n = \pm 0.005$ Hz

$$\begin{aligned}
 U_\zeta &= \pm \left[\left(\frac{d\zeta}{d\omega_d} U\omega_d \right)^2 + \left(\frac{d\zeta}{d\omega_n} U\omega_n \right)^2 \right]^{1/2} \\
 &= \pm \left[(-1.24 \times 0.2)^2 + (0.481 \times 0.005)^2 \right]^{1/2} \\
 &= \pm 0.248 \text{ Hz}
 \end{aligned}$$

The uncertainties of both frequencies are due to resolution effects. The uncertainty of damped frequency is dominated and the uncertainty of natural frequency is negligible. Hence, the uncertainty of damping coefficient is mainly influenced by the uncertainty of damped frequency.

Conclusion

After performing a vibration analysis on a DODVS frame and determining the damped frequency of the system, the theoretical natural frequency was calculated in ANSYS. Knowing these two values, the damping coefficient was determined. The deliverable measurement defined in the method section of this document stated that the frequencies affecting the system were to be determined by testing the DODVS. Those measured frequencies were to be given to the Xerox sponsored capstone team to aide in their design of the new DODVS. In addition to the frequencies of the system, the

damping coefficient was calculated; this value will be used by the Xerox team for benchmarking purposes when their final analysis/ Product Design Specification (PDS) comparison is completed in the coming months. The analysis performed in this experiment will aid in the development of the new DODVS, which will in-turn, help researches better the quality and efficiency of Xerox solid ink printers. The vibration analysis performed required skills that will be useful in an industrial atmosphere or for research performed at the graduate level. The students who performed this experiment have gained practical experience and will be well suited if a similar analysis needs to be performed by them in the future.

Appendix E.1.A: Apparatus

- Drop on Drum Vision System (DODVS)
- 4 strain gages
- Strain gage application chemicals and supplies
- Voltage amplifier
- 2 clamps
- Digital voltmeter
- 120 Ω resistors for bridge circuit
- Proto-board
- Data acquisition system and computer running LabView

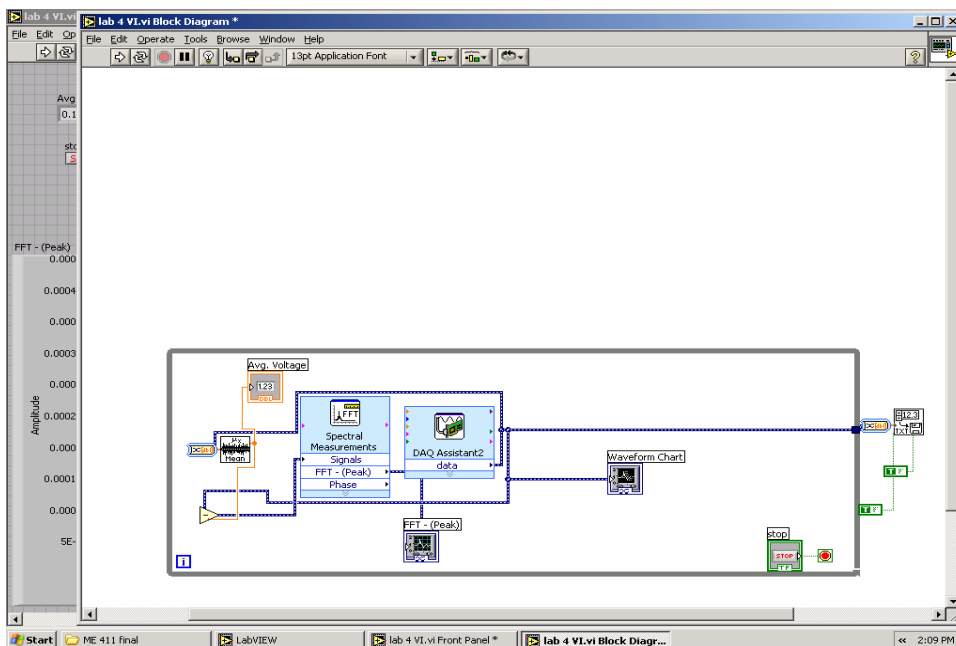


Figure E.A-1: Various supplies to install a strain gage include an installation guide, gages, cleansing chemicals, abrasive sand paper, adhesive, a soldering iron, and related supplies.



Figure E.A-2: Proto-board.

Appendix E.1.B: VI Presentations



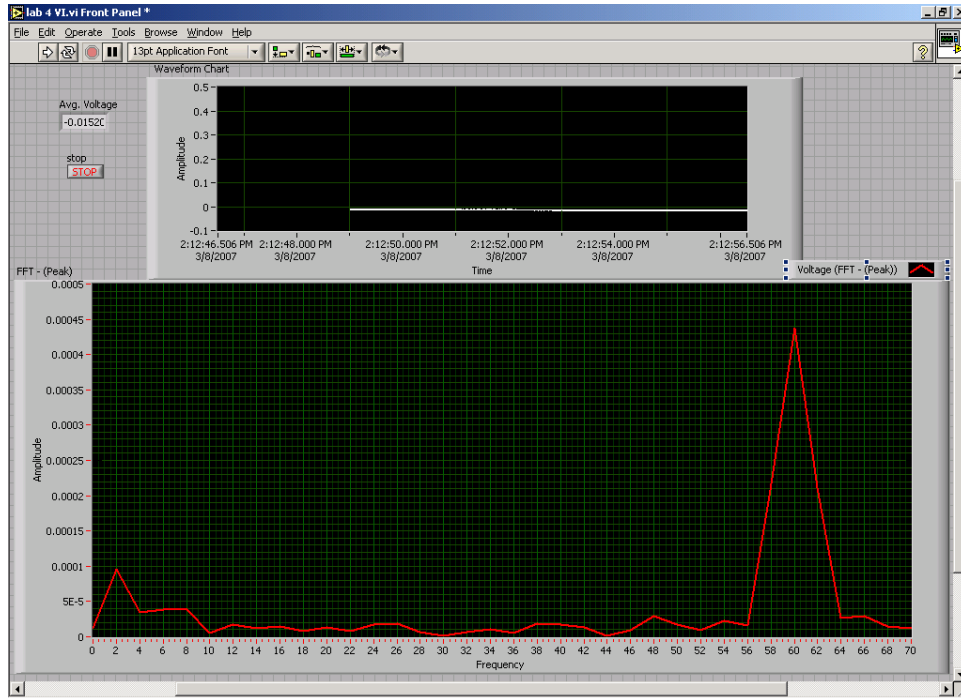


Figure E.1.B-1: Screenshots of VI block diagram and front panel.

Appendix E.2

Vibration analysis of new DODVS

Objective

The objective of this experiment is to mount strain gages onto the surface of the new DODVS and perform a vibration analysis to validate the calculations in Appendix D. For this experiment the same setup will be used as was used in the original experiment to eliminate any error that may be caused any differences in the methods of the experiment. The same LabView Virtual Instrument (VI) will be used, and the data will be interpreted by the same Fast Fourier Transform (FFT). To see the VI, circuit diagrams and experiment theory, see appendix E.1.

Method

For this experiment a VI was written in LabView that would collect the voltage signal from the bridge circuit and display the data in the form of an FFT and a direct measure of the voltage in real-time. After setting up the VI, the next steps were applying the strain gages, making sure they were functioning properly and resolving any issues that were hindering the quality of the data. Two strain gages were placed on the DODVS frame:

- SG 2 was placed on the right side rear gusset 0.5 inch in from the edge and 3 inches up from the bottom.

With the locations of strain gages determined, the next step was to apply them: the first step was to sand the location where the gage was to be placed with 220 grit sandpaper. Following that, the surface was wet-sanded with 320 grit sandpaper and degreaser, followed by wiping the surface down with degreaser. The surface was then prepped with conditioner and a neutralizer. The strain gage was then picked up with four inches of cellophane tape (terminal side up) and placed along scribe marks laid down to indicate its final position. With the tape folded back, a solution of isopropyl alcohol was applied to surface of the gage and it was allowed to dry. The gage was then glued to the surface and held in place for three minutes with significant pressure from the installers thumb. Once the glue had dried the lead wires were soldered into place and tested by checking the resistance of the gage. The gage application process was identical for all four gages.

With the gages set up, the bridge circuit was created on a proto-board and the output voltage was run through an amplifier circuit with the gain set to 100. The output voltage from the amplifier was then input into the Data Acquisition card (DAQ) and LabView collected the data. A photograph of the setup for this experiment can be seen in Figure 3.

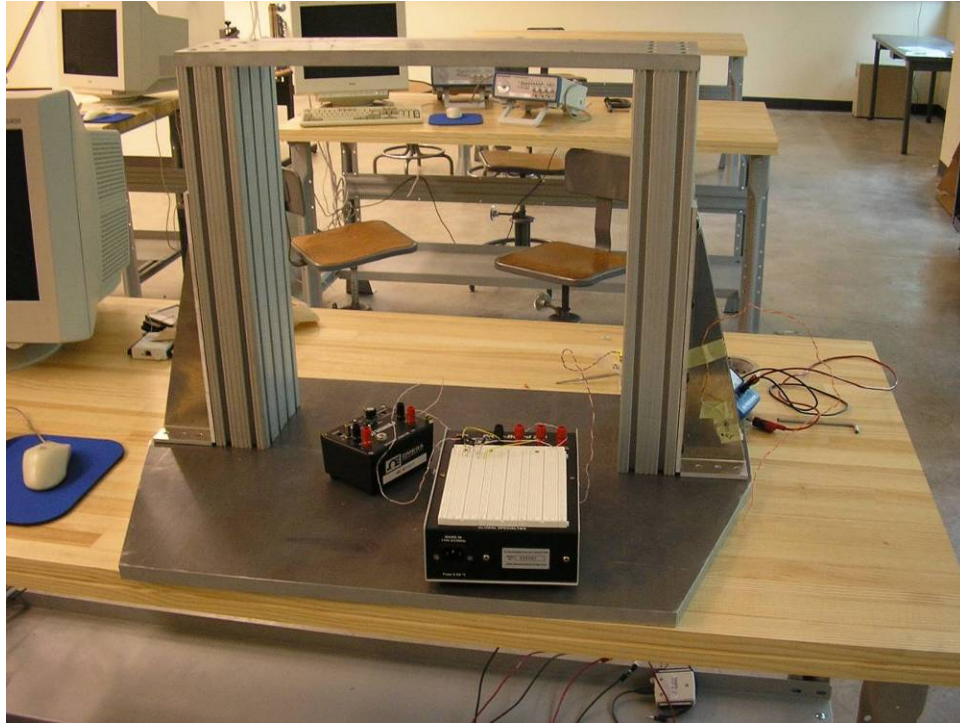


Figure E.2. 6: The DODVS frame with strain gages attached and connected to a bridge circuit as the fourth resistor.

Data Collection

Once the system had been setup, as seen in figure three, the data collection process was started. For this experiment, there was no need to calibrate the gages because the only data that mattered was the damped frequency, which was determined by the Fast Fourier transform. To determine the damped frequency, the system was set into oscillation by applying a nominal impact load. The problem we had with the new system is that it was far too rigid to cleanly deflect. To get a change 1 mV change in the output voltage from the bridge circuit a load of 96.58 lbs would need to be applied (see appendix D).

For strain gages 1 and 2 this procedure was replicated three times to validate the data.

Analysis

The FFT was setup to collect data at 10 KHz continuously; doing so would eliminate any chance of interference from the Nyquist frequency (and any associated alias frequencies) and would provide more accurate data than if a much lower sampling rate was chosen.

The data the experiment yielded was not what was desired when the experiment began. The frequencies detected by the FFT were all over the spectrum and can be attributed to the vibrations of items in the room; these items were most likely set into oscillation as the impact load was applied to the DODVS frame. Due to the inability to properly deflect the system, the strain gage only detected the impulse load, which was only creating a change of 0.003 mV at the moment of impact and would immediately damp back to the mean output voltage of the bridge circuit.

The data was inaccurate, but did provide a few glimpses of hope. The frequencies detected by SG 1 were the ubiquitous 60 Hz from AC powered electronics; the 2 Hz frequency was most likely the table rocking, the 12 HZ frequency was assumed to be the monitor, but the 22 HZ frequency in all likelihood was the damped frequency of the DODVS.

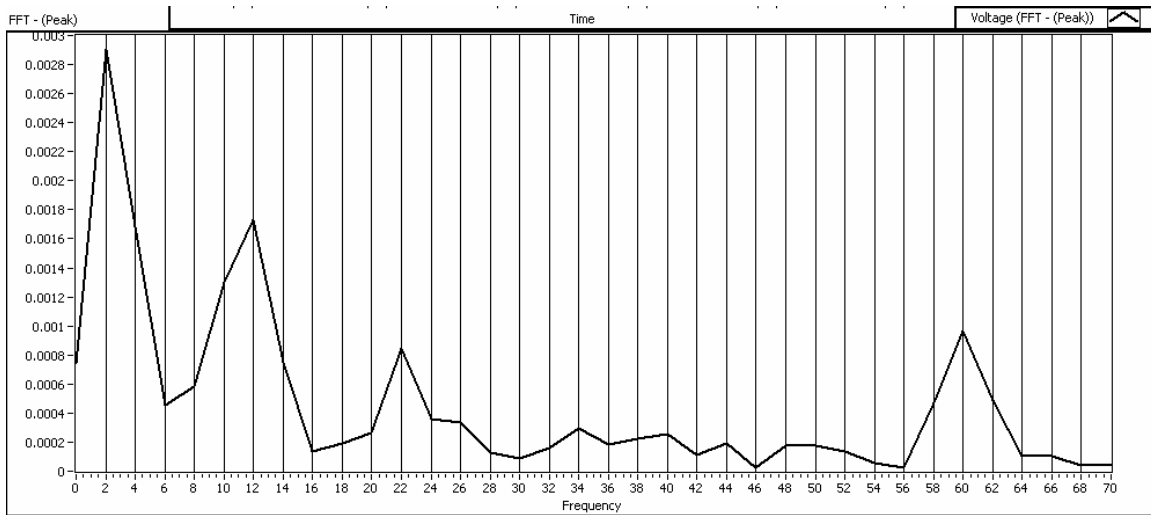


Figure E.2. 7: Frequencies detected by SG 1.

Although the data in Figure E.4 isn't exactly concrete evidence, the data collected by SG 2 didn't collect anything but the 60 Hz frequency of electronics running on AC current.

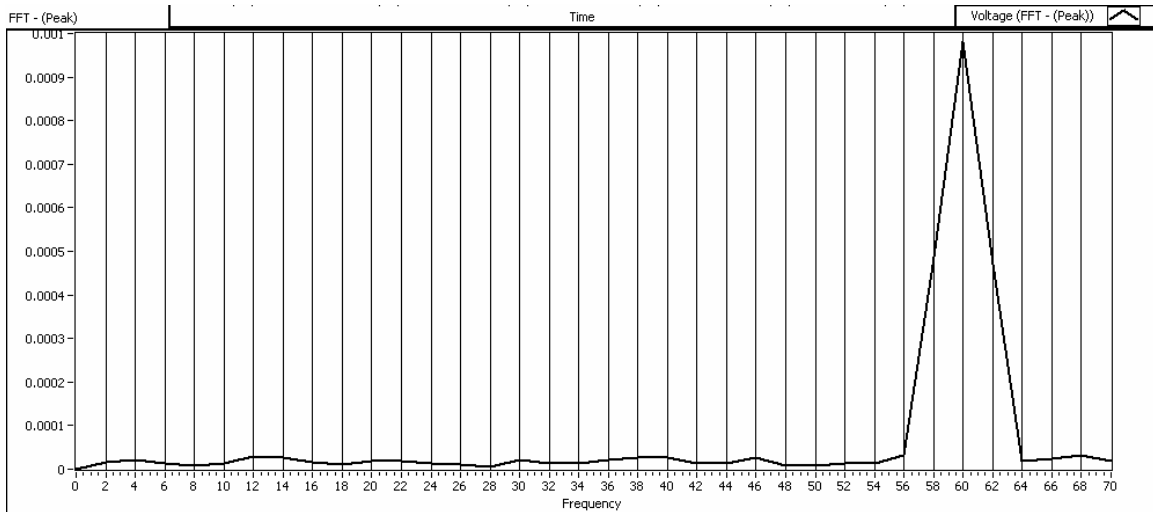


Figure E.2. 8: Frequencies detected by SG 2.

Conclusions

Due to our inability to deflect the frame enough to cause a significant change in the output voltage of the bridge circuit, there cannot be any conclusions drawn from the collected data. Although one of the frequencies detected by SG 1 was 22 Hz, which is in the anticipated range for the new system, there was too much noise to have any confidence in knowing that it was the frequency of the system. However, one thing that was learned was that the new DODVS will not deflect appreciably under normal operating loads (a maximum force of 10 N). The only conclusions that can be drawn about the natural/damped frequency come from the ANSYS model that predicted a worse case scenario natural frequency of 18 Hz (see appendix D).

Appendix E.3

Vibration analysis of fifth-floor table vibrations.

Objective

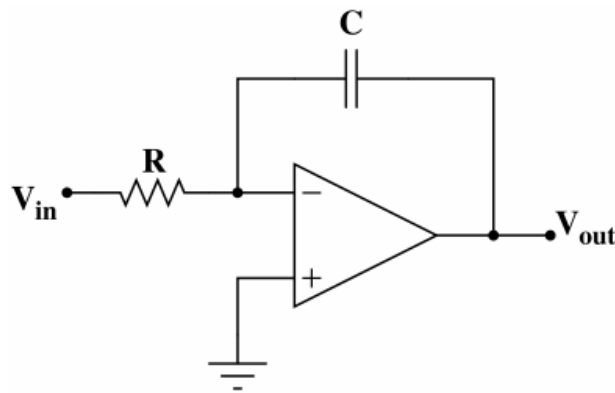
The purpose of this experiment is to determine the vibration frequency and relative amplitude of the fifth floor fluid mechanics lab, and two tables. The Xerox capstone team needs this information to determine if the vibration problems of an existing device stem

from problems with the floor, table or only the device itself. This report will also offer recommendations to the Xerox Capstone Team on ways vibration could be reduced on the mounting of their device.

Theory and Background

A piezoelectric element (or crystal) is an object which generates a voltage difference when subjected to a change in shape. A change in shape is caused by a change in force, which implies that the piezoelectric element may be used to measure jerk (the rate of change of acceleration with respect to time).

A piezoelectric accelerometer is a device that uses a piezoelectric element to measure vibrations. “Accelerometer” is a misnomer since the piezoelectric element itself measures jerk, not acceleration. Voltage signals outputted by the accelerometer may be amplified and simultaneously integrated with respect to time to obtain measurable voltage signals proportional to the actual acceleration. This is normally done with an op-amp integrator circuit [1]:



$$V_{\text{out}} = \int_0^t -\frac{V_{\text{in}}}{RC} dt + V_{\text{initial}}$$

V_{in} is the (weak) jerk signal from an accelerometer, and V_{out} is the amplified and integrated signal representing (proportional to) acceleration. Figure 1 shows the basic internal workings of a piezoelectric accelerometer and the amplifier that goes with it.

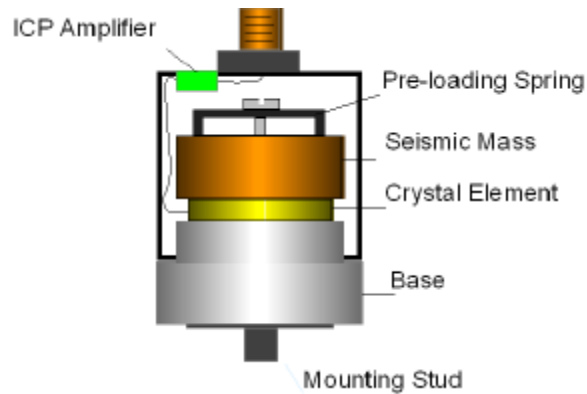
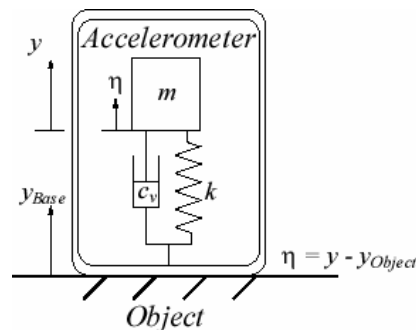


Figure E.3.1: Internal workings of a piezoelectric accelerometer. Graphic from dliengineering.com

Piezoelectric accelerometers used in practice consist of a seismic mass, loading spring, piezoelectric crystal, and base. When the accelerometer is subjected to any change in force that causes the seismic mass to change the amount of pressure subjected to the piezoelectric crystal, the crystal deforms, and generates a small voltage signal. This signal is then amplified to a signal readable by a data acquisition card. The special shape and arrangement of the mass and element alongside the action of the spring are intended to ensure that the accelerometer will measure acceleration along one axis only. All three axes are measured with three accelerometers.

When an accelerometer is attached to a moving object or base it can be modeled as a single degree-of-freedom vibration system.



The free body diagram of the system above is shown below,

$$\begin{array}{ccc}
 \mathbf{F} & = & \mathbf{ma} \\
 \begin{array}{c} \square \\ \downarrow c_v(\dot{y}-\dot{y}_{Object}) \\ = c_v\dot{\eta} \quad \downarrow k(y-y_{Object}) \\ = k\eta \end{array} & = & \begin{array}{c} \square \\ \uparrow \\ m\ddot{y} = m(\ddot{\eta} + \ddot{y}_{Object}) \end{array}
 \end{array}$$

The equation of motion for the sensor may be written:

$$m\ddot{\eta} + c_v\dot{\eta} + k\eta = -m\ddot{y}_{Object}$$

To simplify the forcing function, it is assumed that the base is under harmonic excitation, so that:

$$y_{Object} = Y_{Object} \sin(\omega t)$$

The equation of motion then becomes:

$$m\ddot{\eta} + c_v\dot{\eta} + k\eta = m\omega^2 Y_{Object} \ddot{y}_{Object}$$

It can be shown [2] that for common accelerometer constructions, the displacement response of the element is very closely given by:

$$\eta(t) = \left(\frac{\omega}{\omega_n}\right)^2 Y_{Object} \sin(\omega t - \phi)$$

This approximation is very good at least up to 5 kHz for most sensors. This result is crucial since it is stating that the frequencies seen by the accelerometer are equal to the frequencies being measured.

The measured vibrations are by no means representative of simple harmonic motion. Some ‘‘Periodicity’’ does exist, however the vibrations are very random. This suggests the

use of the discrete Fourier transform as a good method to obtain frequency information. The transform is given by:

$$X_k = \sum_{n=0}^{N-1} x_n e^{-\frac{2\pi i}{N}kn} \quad k = 0, \dots, N - 1$$

Where x_n is the (discrete) signal, N is the number of samples and X_k is the transformed signal, generally a complex number. The frequencies are given by (T representing the sampling period):

$$\omega_k = \frac{2\pi k}{NT} \quad (1)$$

And the amplitudes corresponding to these frequencies are $|X_k|$.

Methods and Apparatus

To log and measure the vibrations of interest, three high sensitivity Endevco accelerometers (professionally calibrated) were selected, and attached to a 2 x 2.625 x 1 inch block of steel. This formed a probe that could be easily placed on a surface. The outputs of the accelerometers were fed into Bruel and Kjaer integrating amplifiers, seen in figure 2. To ensure the accelerometers were working correctly, they were manually shaken along each axis and the live results observed. The peaks on the live data stream directly correlated to the motion of the accelerometers, so proper operation was verified.

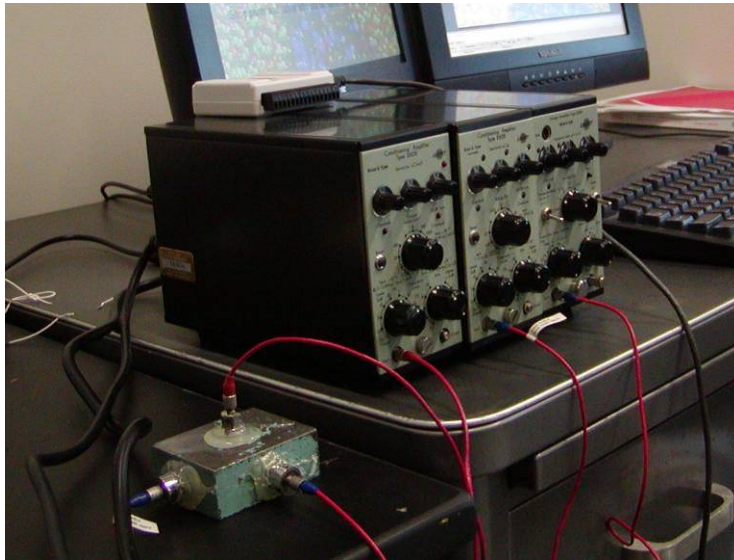


Figure E.3.2: Experiment apparatus. The accelerometers can be seen on the left, and the 3 amplifiers are in the middle

A 12 bit National Instruments data acquisition USB device was used to record that data into a computer running LabVIEW. Sampling frequencies ranged from 25 Hz to 1 kHz. The accelerometers were identified by their orientation: North, West, and Vertical. Measurements were taken by simply placing the probe on the surface of interest and then recording the signals on the computer. Table 1 shows a summary of the experiments done.

Number	Sample frequency, Hz	Experiment detail
1	25	Floor vibrations.
2	1000	Floor vibrations.
3	25	Vibrations of low, stiff table.

4	25	Vibrations of tall, less stiff table.
---	----	---------------------------------------

Table E.3.1: The experiments

The table vibration measurements each consisted of (in order shown):

- Ten seconds of steady state
- Impulse along north
- Impulse along northwest
- Impulse along west

Results and Discussion

This experiment was conducted in two parts: measurement of the building vibration and response to outside disturbances; and measurement of the vibration characteristics of two tables used by the Xerox team to support their apparatus. The quantities of interest are the natural frequencies and the characteristic response times.

Natural frequencies are considered first. Figure 3 shows sample vibration data of the north and west accelerometers over 15 seconds each (floor data shown. Table data is similar). From the raw data plots, it is difficult to discern a clear frequency for the vibrations. To aid in finding the true frequencies present in the data, discrete Fourier transformations were applied. Figure 4 shows the normalized frequency spectra of the floor and (steady state) tables: graphs of $|X_k|$ vs frequency (not angular) calculated through equation 1.

Due to very high amplifier gain and minute signals, the raw data was noisy and unsmooth. To amend this, the vibrations were sampled at high frequencies and moving averages applied to the results.

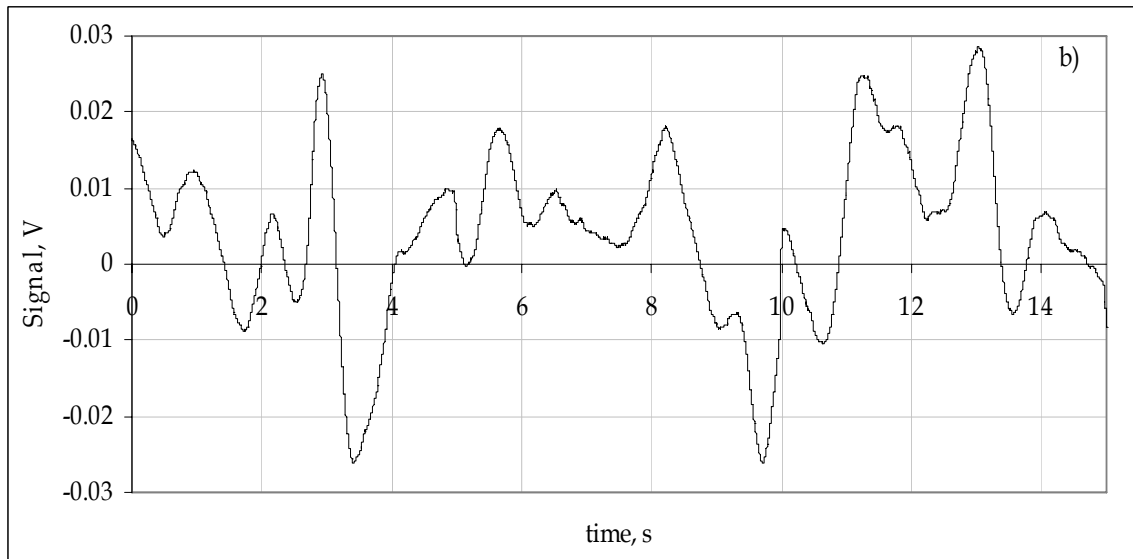
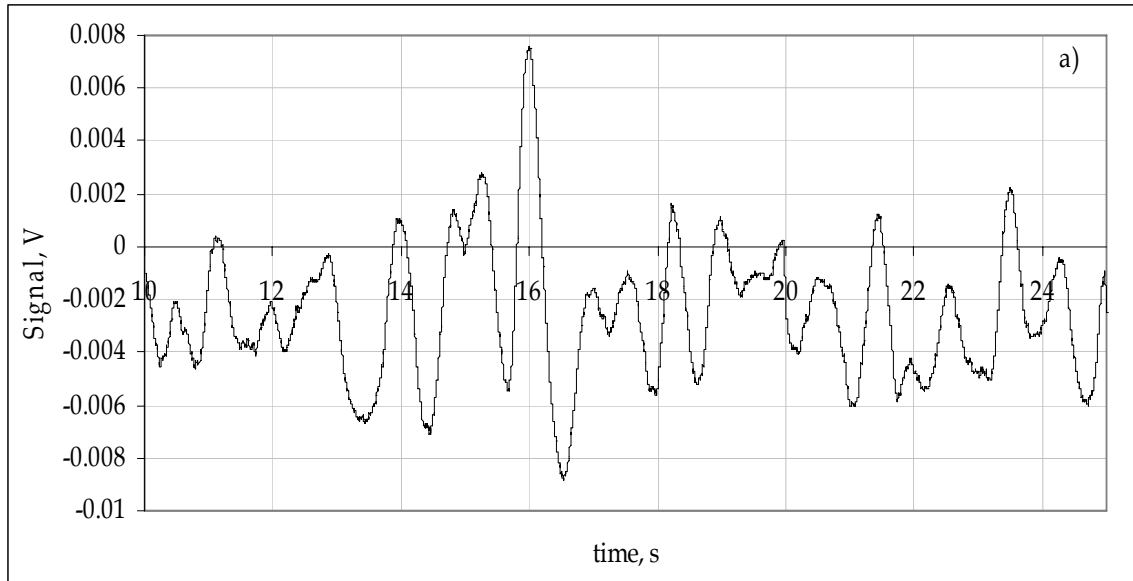


Figure E.3.3: Sample vibration of the floor a,) west; b) north

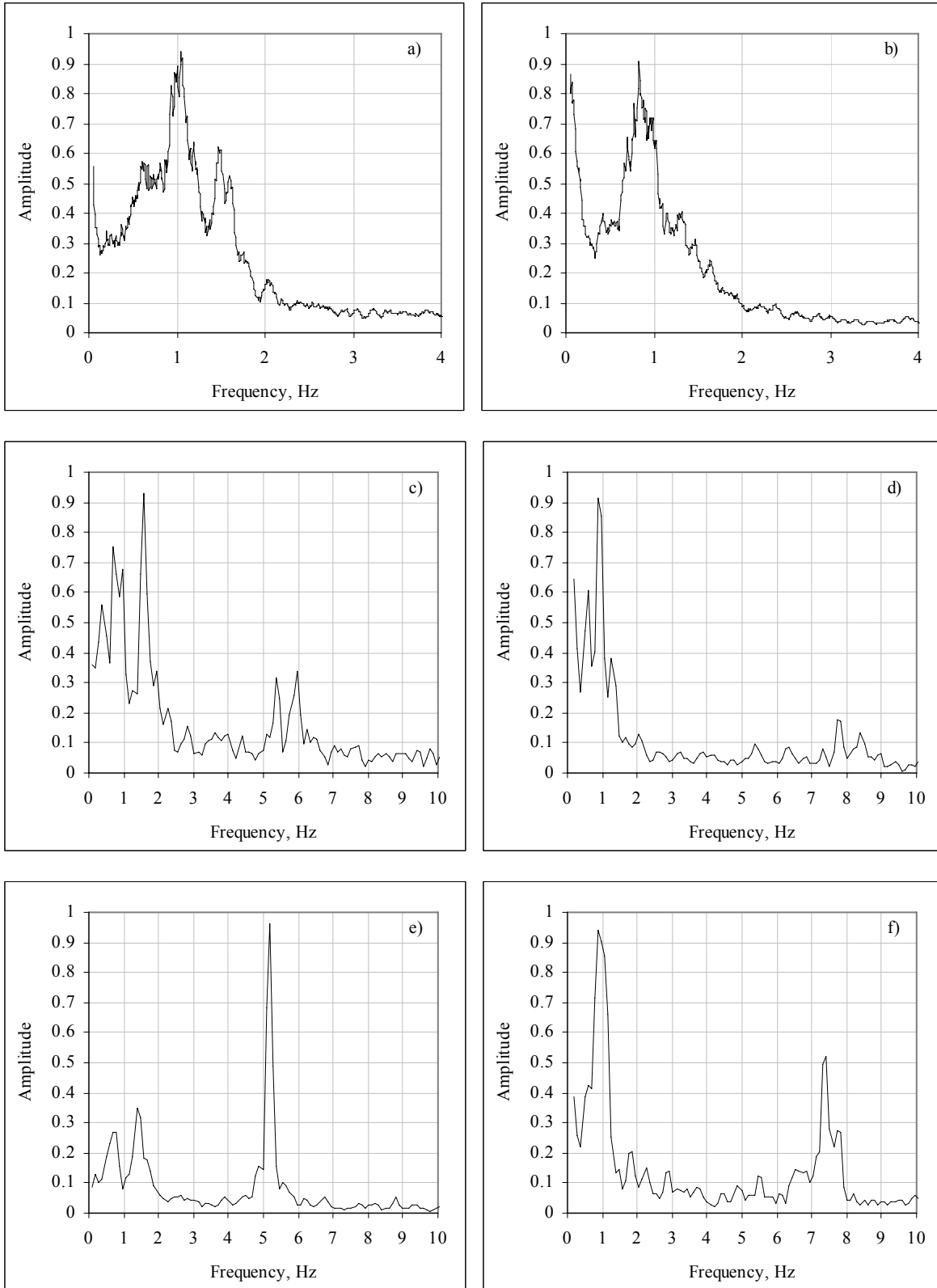


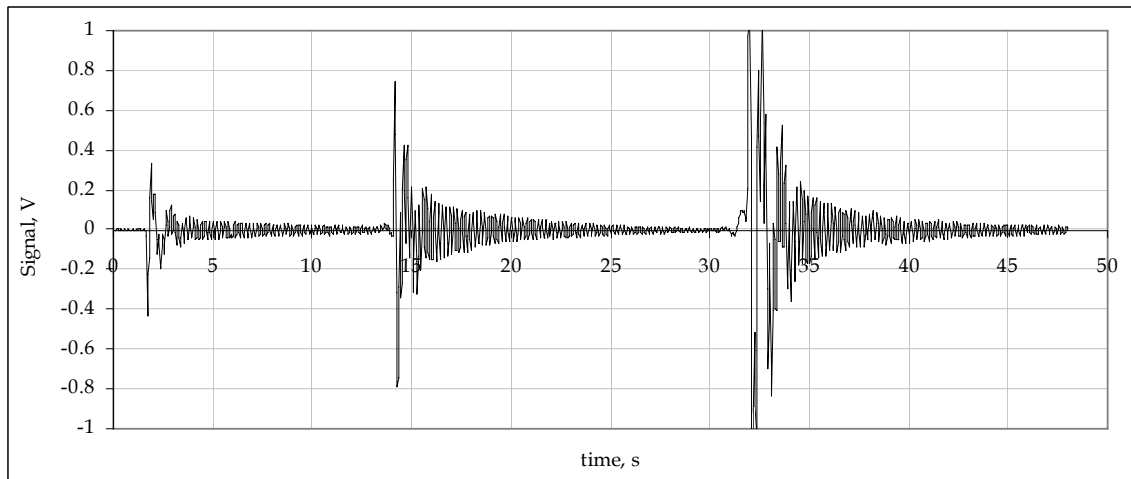
Figure E.3.4: Fourier transforms of the experiments: a) floor, west; b) floor, north; c) low table, west; d) low table, north; e) high table, west; f) high table, north

From the Fourier transformation plots of the floor (4a and 4b), it is clear that the most prevalent frequency occurs at just below 1 Hz, which is reasonable for a building the size of the engineering building at PSU.

The low, stiff table showed slightly higher frequency than the floor it sits on. Also, the frequencies involved differ noticeably when comparing the west (4c) to north (4d) vibrations. The table is longer along the west axis, and the resulting frequencies are greater compared to the north axis. This implies that the table is stiffer along its long dimension.

The tall, less stiff table showed vaguely similar trends compared to its stiffer counterpart. It vibrates at a significantly higher frequency along the west axis (4e, 5 Hz), and shows both low and high frequencies along its north axis (4d, 1 and 7 Hz).

To characterize response times, the tables were bumped along the north, northwest, and west axes respectively. Figure 5 shows the example response of the tall table along its west (long) axis.



The characteristic dampening response time of these disturbances was measured by fitting an exponential “envelope” curve to the transient portions following impulses, and then simply extracting the response time.

Conclusion

Item	Dominant frequency, Hz	Response time
Floor, west	1	One to two cycles
Floor, north	0.8	One to two cycles
Low table, west	1 to 2	0.6 s
Low table, north	1	0.6 s
Tall table, west	5.2	4.5 s
Tall table, north	1	0.75 s

Table E.3.2: Summary of findings

The Xerox Capstone Team was concerned that vibration from fifth floor of the engineering building at PSU could cause their device not to function as well as expected. The current frame in use is predicted to have a natural frequency of around 10 Hz (currently being tested by a different team), and clearly has a vibration problem. The new frame for the Xerox device has a predicted natural frequency of well over 20 Hz. With the natural frequency of the floor being around 1 Hz, **the floor vibrations should have no effect on the new device operation.**

The two tables used by the Xerox team to support their device were also thought to be a problem. The natural frequency of the stiff table is around 1 Hz, with a secondary frequency of between 6 and 8 Hz. This is a potential source for the resonance of the current frame, with its low natural frequency nearly matching that of the secondary frequency of the table. **The table should have almost no effect on the new frame**, with its much higher natural frequency. The second taller table was a possible replacement for the low stiffer table should unsatisfactory characteristics be discovered during this experiment. While its natural frequency was surprisingly higher, it took much longer (20+) seconds for the vibration to die out. For this reason, the tall table would be less satisfactory to use than the short stiffer table.

References

- [1] Wikipedia, the free encyclopedia, *Operational amplifier applications*, retrieved 24 March 2007.
<http://en.wikipedia.org/wiki/Operational_amplifier_applications>
- [2] Wikipedia, the free encyclopedia, *Operational amplifier applications*, retrieved 24 March 2007.
< http://www.efunda.com/formulae/vibrations/sdof_eg_accelerometer.cfm>

Appendix E.3.1: Equipment

Quantity	Part Name	Part Number	Settings and other Information
1	Accelerometer	Bruel & Kjaer 4371 1298827	Z direction
2	Accelerometer	Endevco 2224C	X and Y directions
3	Accelerometer cables	B&K 3090C	
2	Charge Amplifier	B&K 2635	316mV/unit out, 1Hz Displ.
1	Charge Amplifier	B&K 2626	1000pC/m/s ² sens.
1	DAQ	NI USB-6008	
1	Computer and USB cable	Dell CPx Laptop computer	Running Lab-View for Data Acquisition. VIs are shown in appendix 3.

Appendix E.4

Image quality comparisons.

Objective



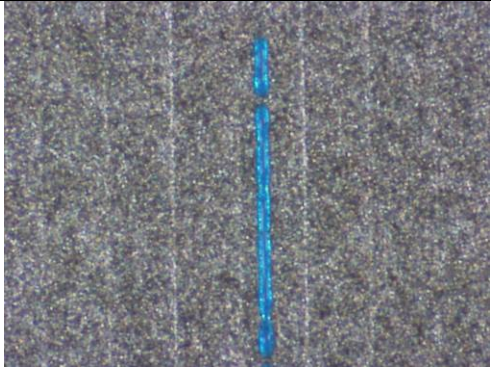
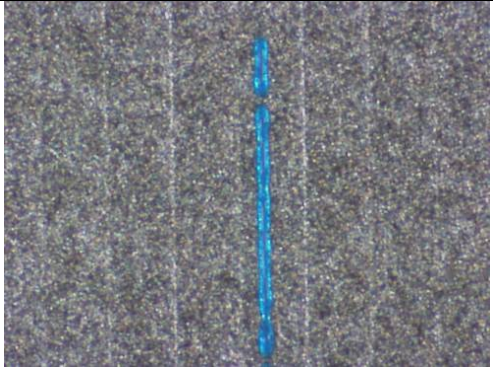
The purpose of this experiment was to obtain verification that improvements made to the DODVS and BTM optical systems did in fact results in improvements in image quality. Since this is a somewhat subjective measure, this will be limited mostly to a presentation of the resulting images and some discussion. The more objective measurements of quality, such as magnification range and optical resolution, are presented elsewhere and are immediately apparent.

Methods and Apparatus

This experiment was carried out using the DODVS and the BTM in the normal operating manner, as described in Appendix C. For the pictures taken with the old DODVS, the previous system was reassembled temporarily as much as possible and images of similar structures were taken for comparison. Images of a single cyan line were used in all cases.

Results and Discussion

The images taken are shown in Table E.4.1. The greater resolution of the new optics configuration is visible, especially at higher magnifications. The two highest magnifications shown cannot be reached by the old configuration.

Magnification	Old DODVS	New DODVS
1.5X		
3X		

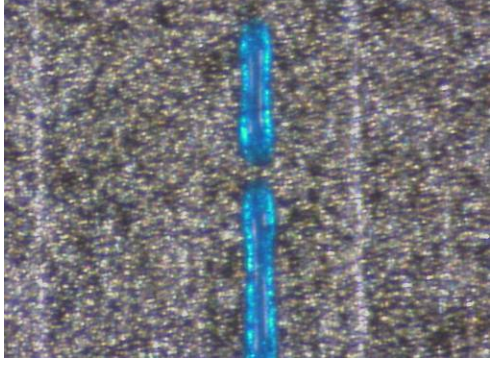
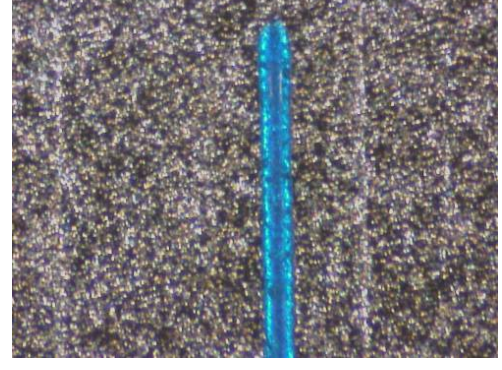
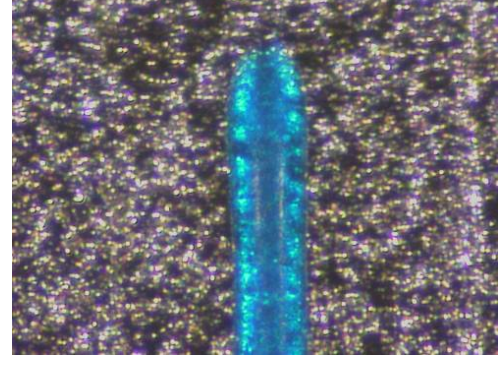
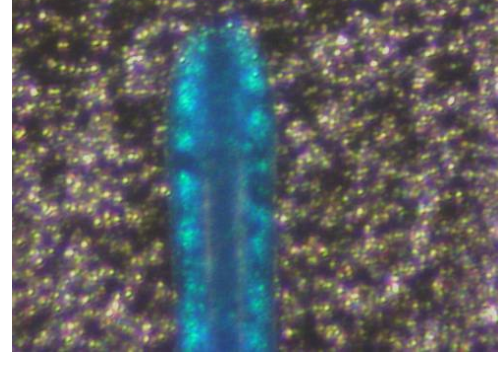


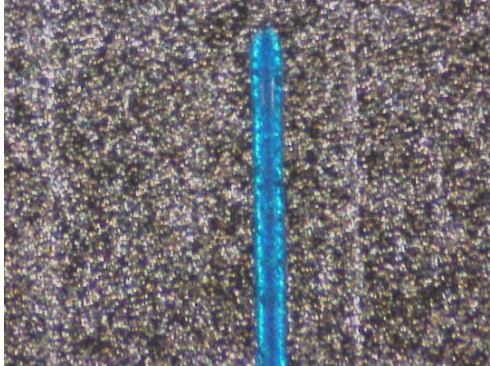

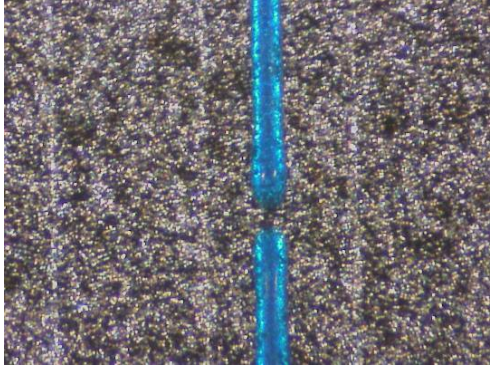

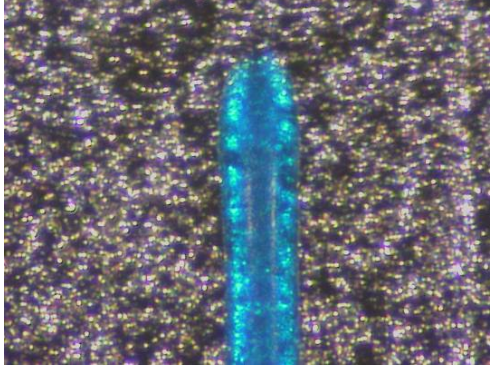

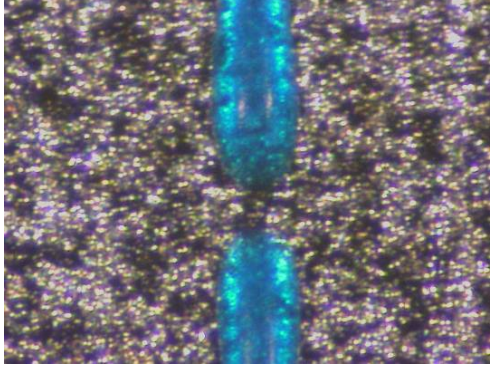
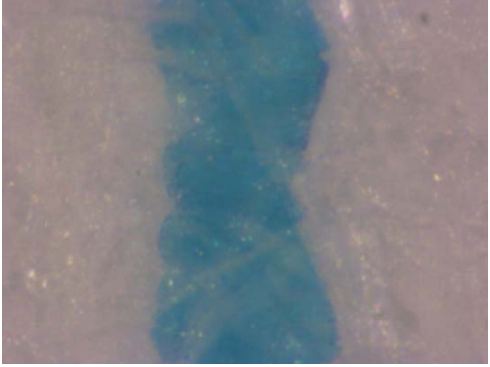
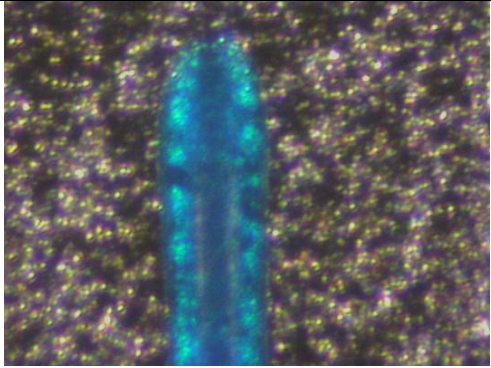
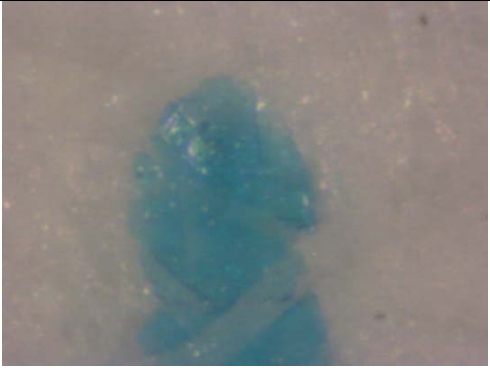
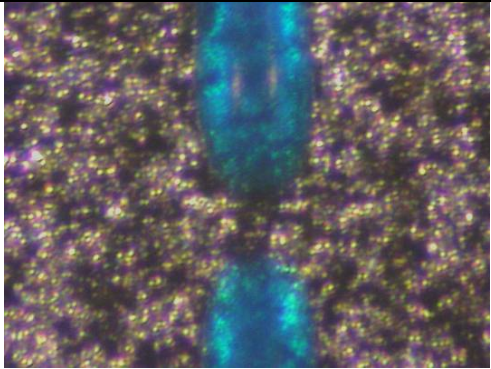

7X		
15X	N/A	
22X	N/A	

Table E.4. 1: Image comparisons between old and new DODVS configurations.

Since the old BTM was essentially unusable, the images taken with it have little basis for comparison. To illustrate the use of the DODVS/BTM system, several pictures were taken of various features at various resolutions using the DODVS, and then of the same features after transfixion to paper, using the BTM. These images are shown in Table E.4.2.

Image	DODVS	BTM
Line (3X)		
Line end (7X)		
Line break (7X)		
Line end (15X)		

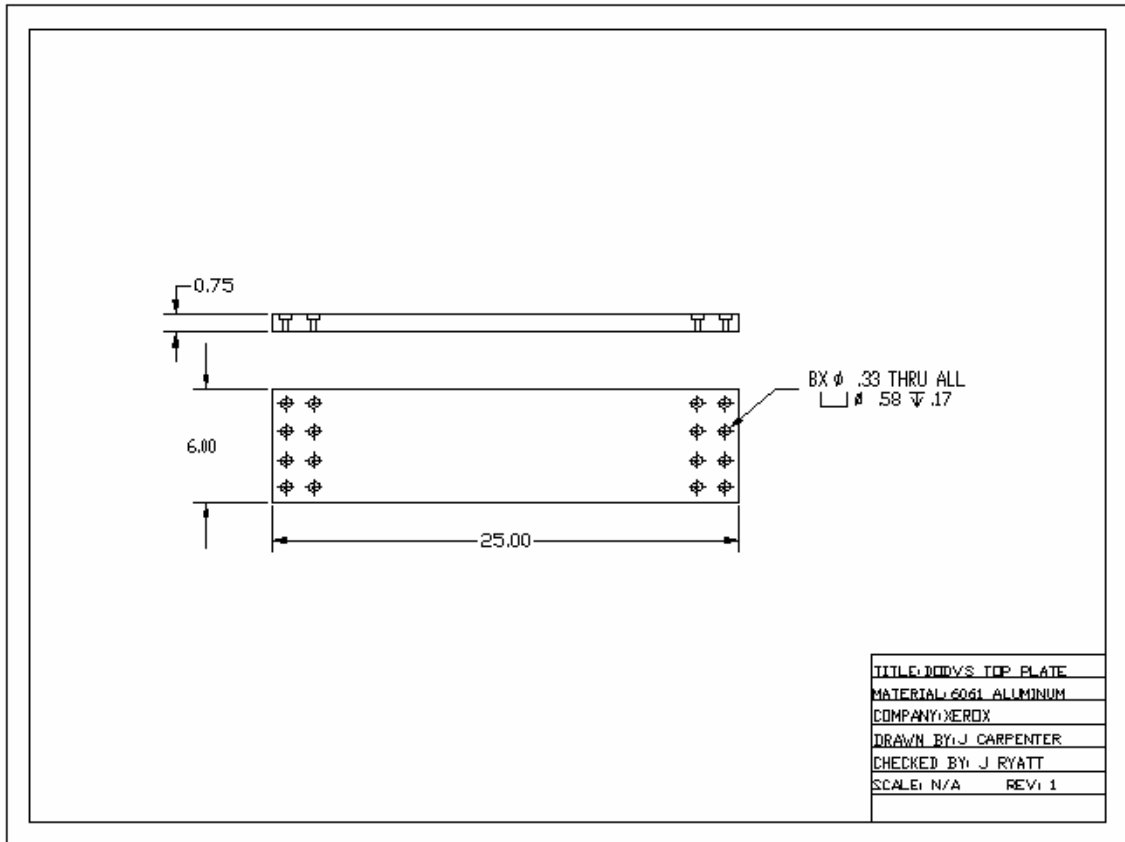
Line break (15X)		
Line end (22X)		
Line break (22X)		

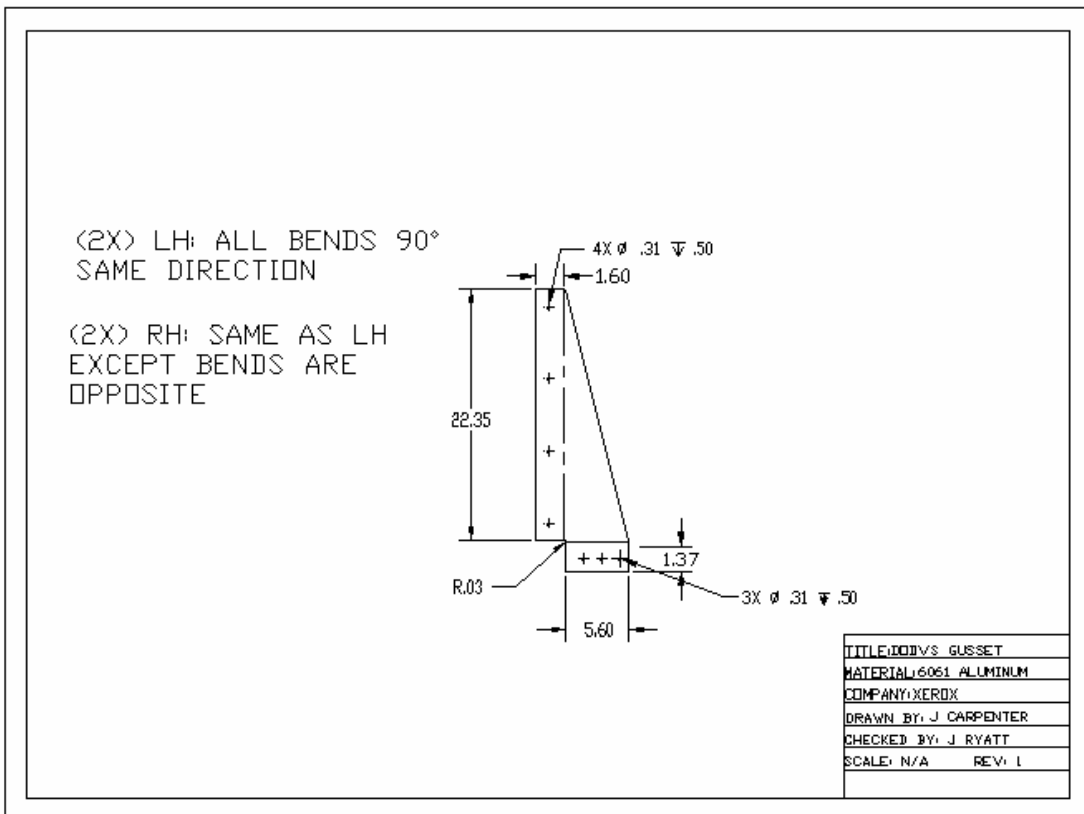
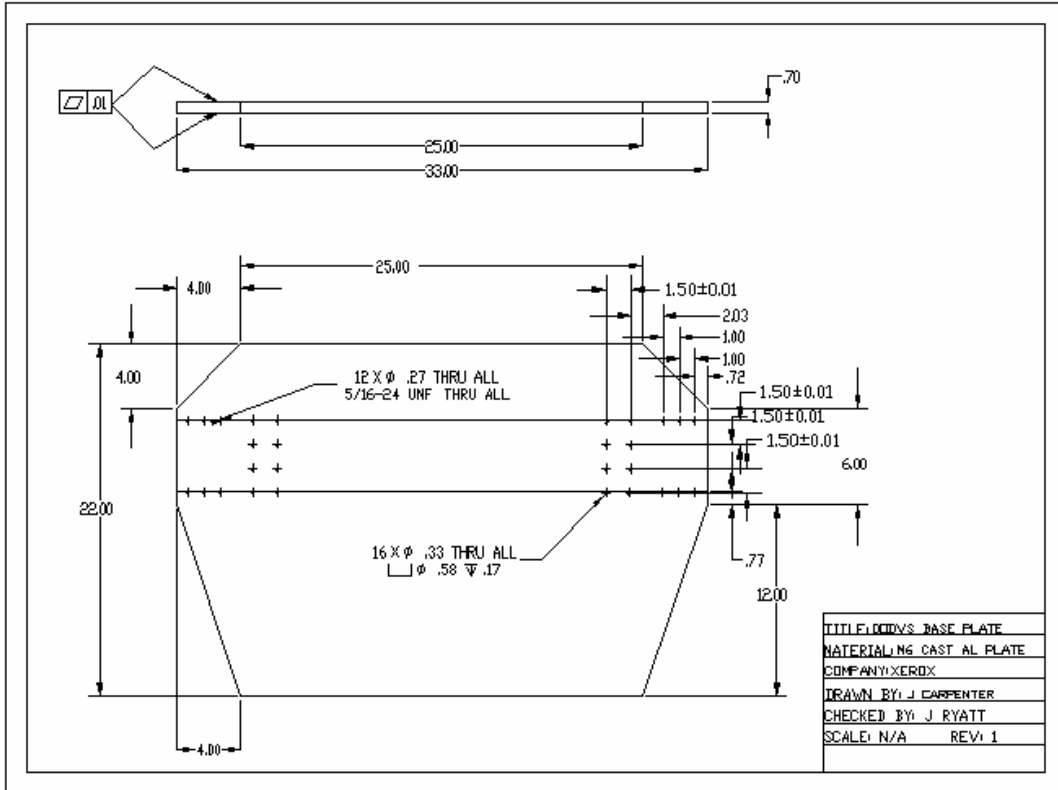
These images demonstrate both that improved images can be obtained from the new DODVS and that the combined system is usable for the intended purpose. Although not obvious in the images above, the new system is also noticeably easier to operate in terms adjusting focus and in less vibration.

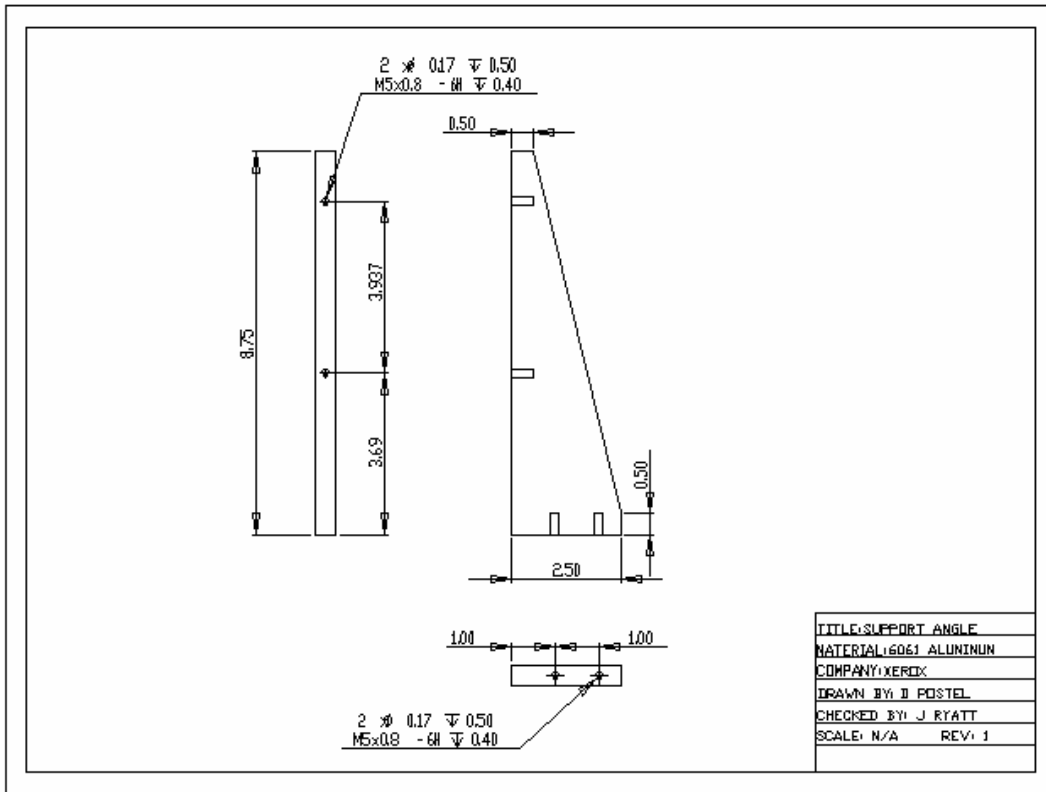
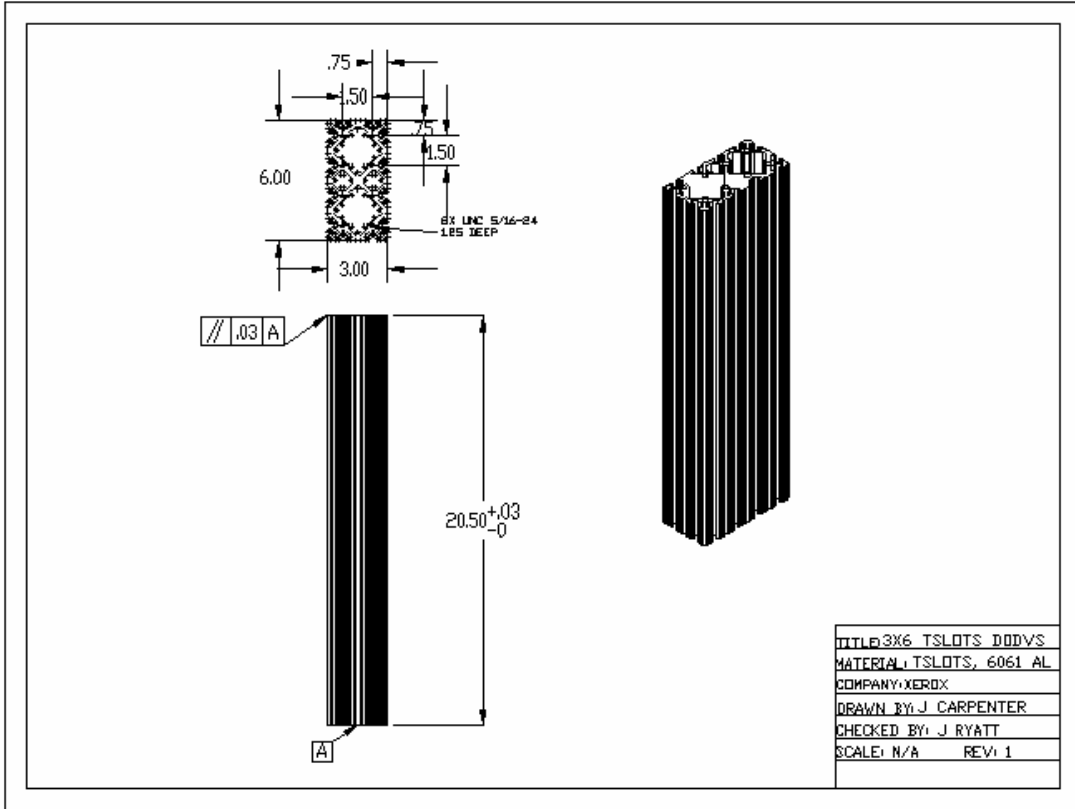
Appendix F: Detailed Part Drawings

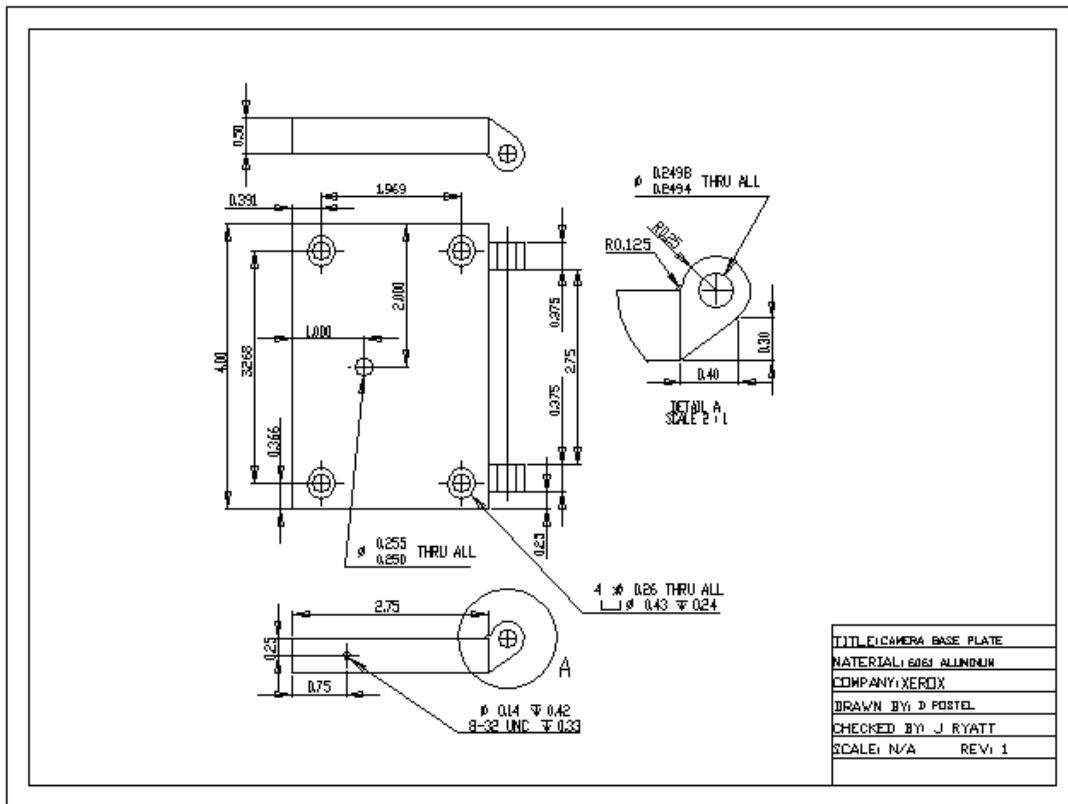
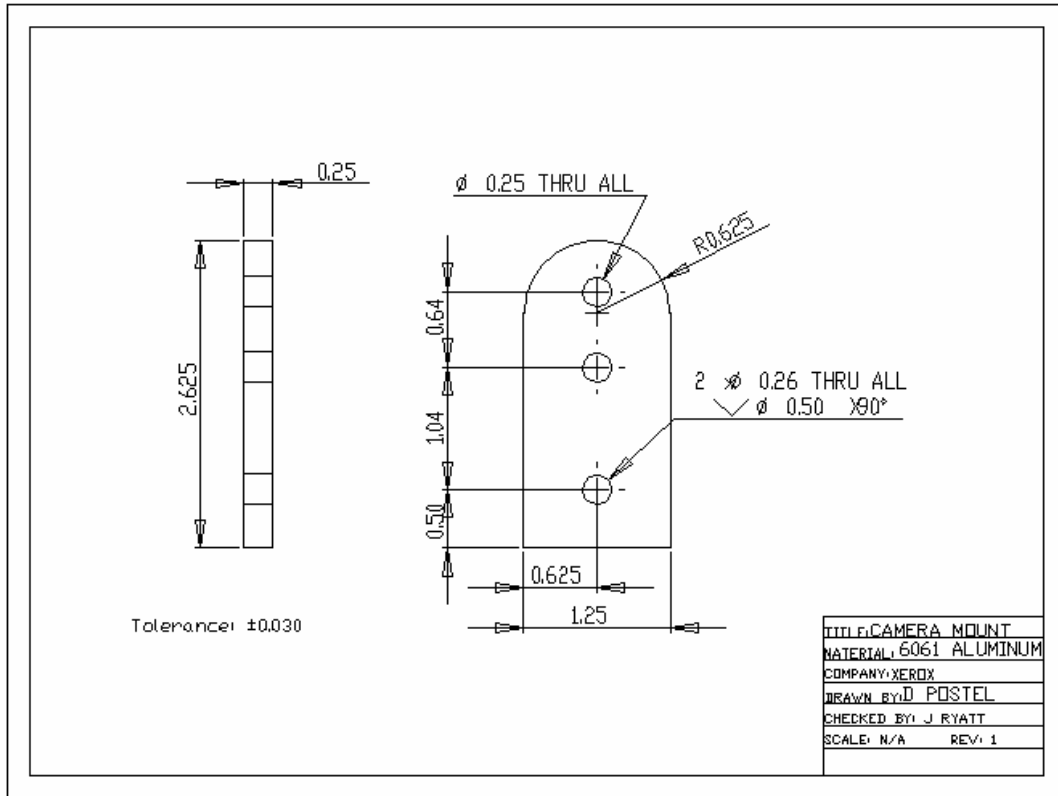
In all drawings, the units are in inches and the two-decimal tolerance is 0.03" unless otherwise specified.

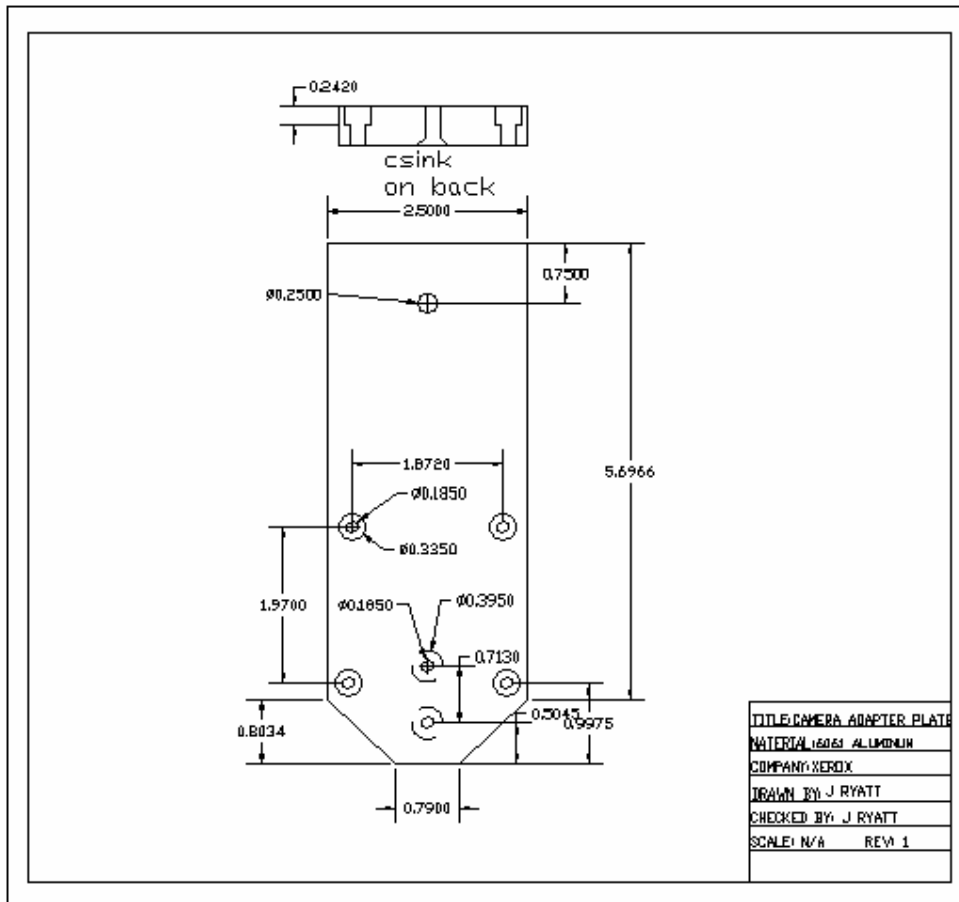
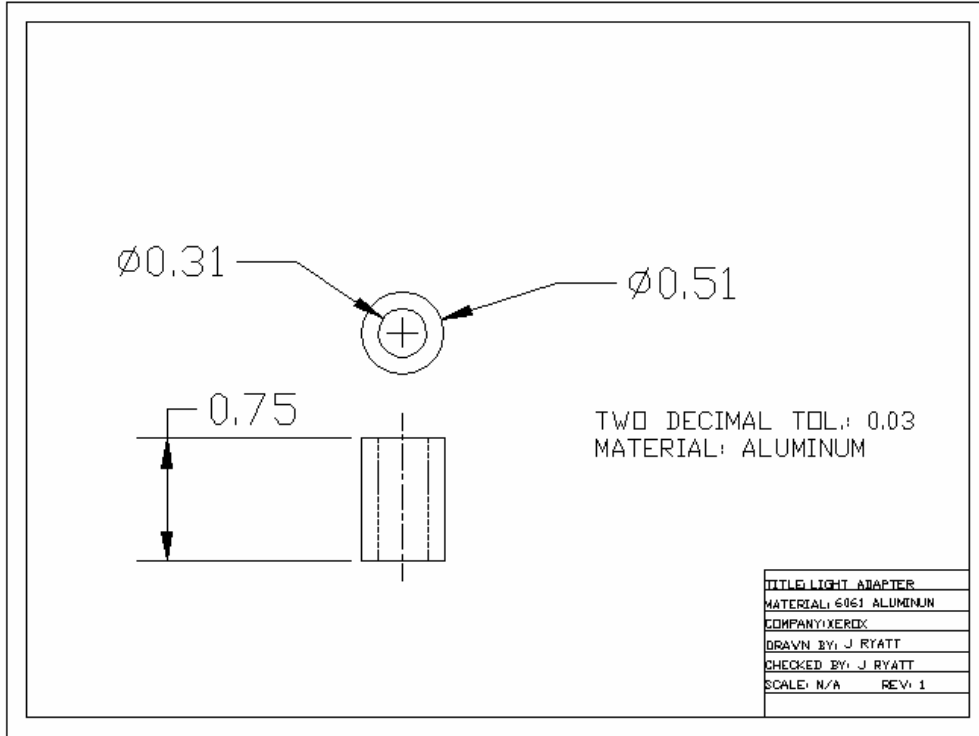
DODVS Drawings

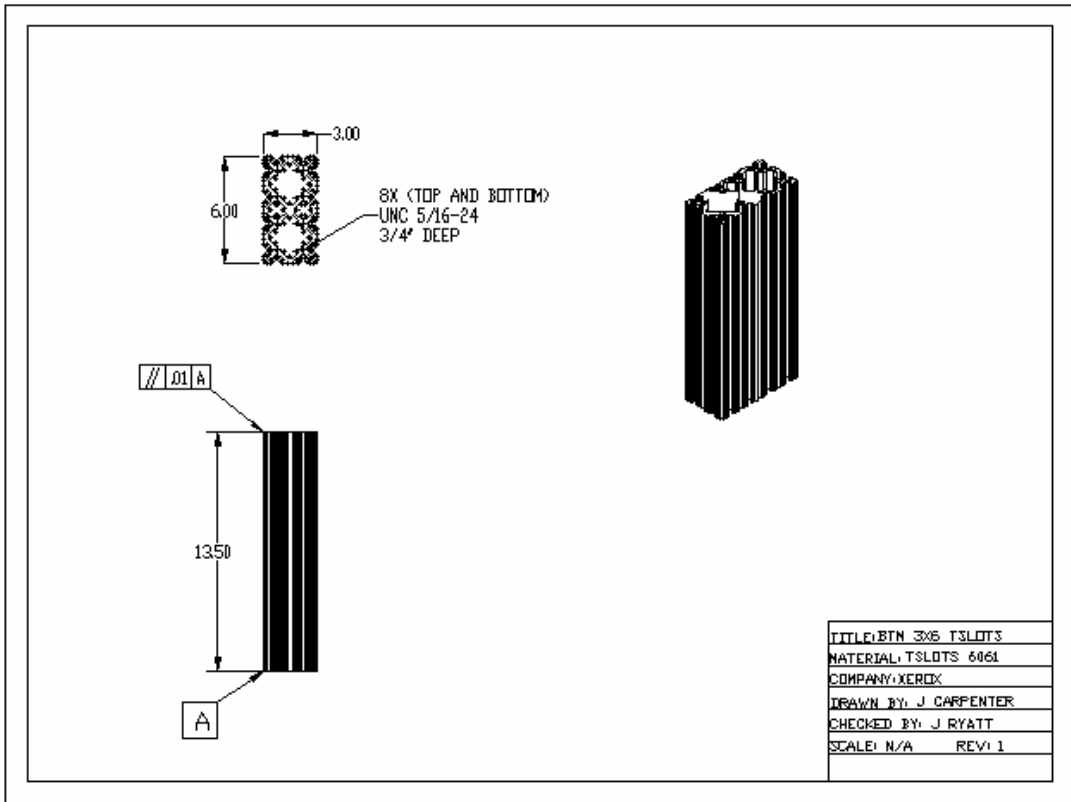
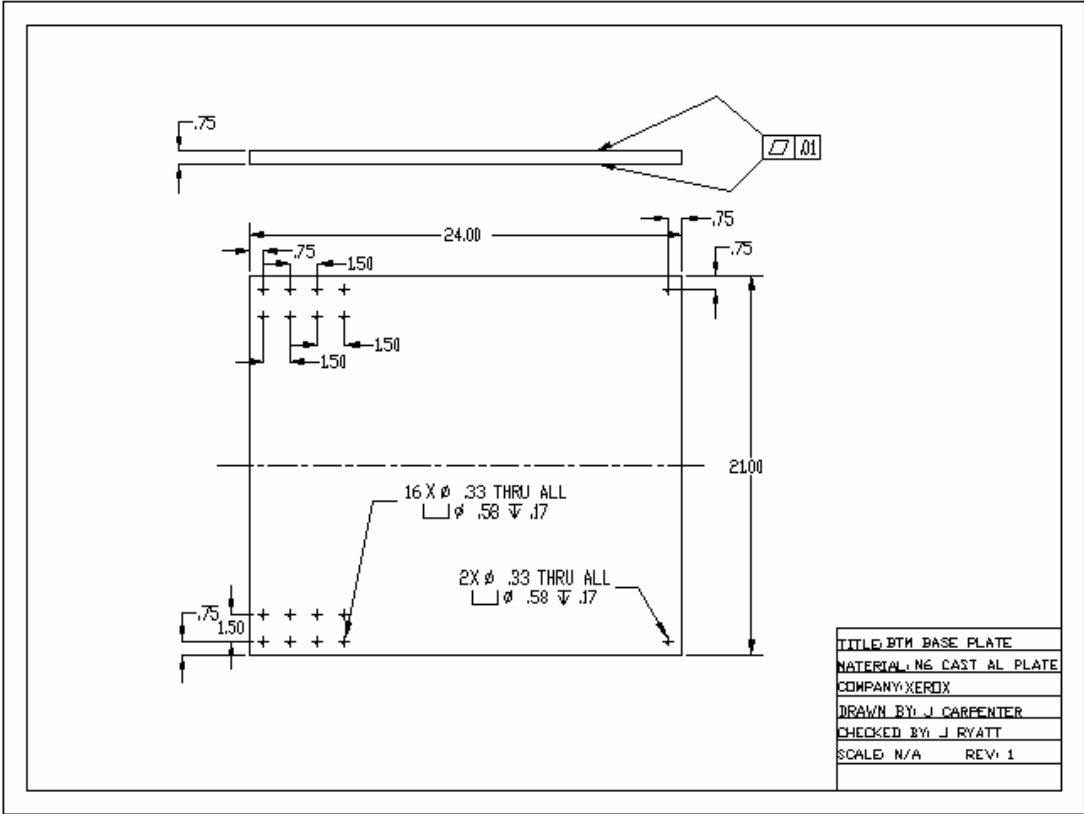


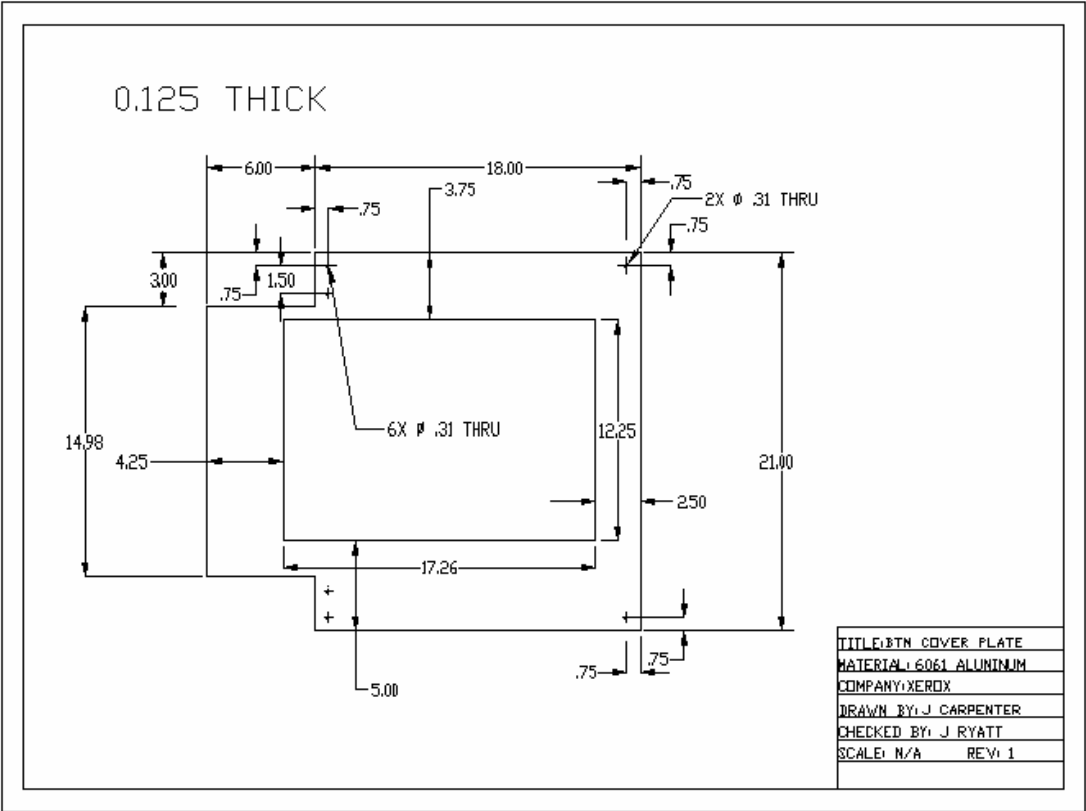
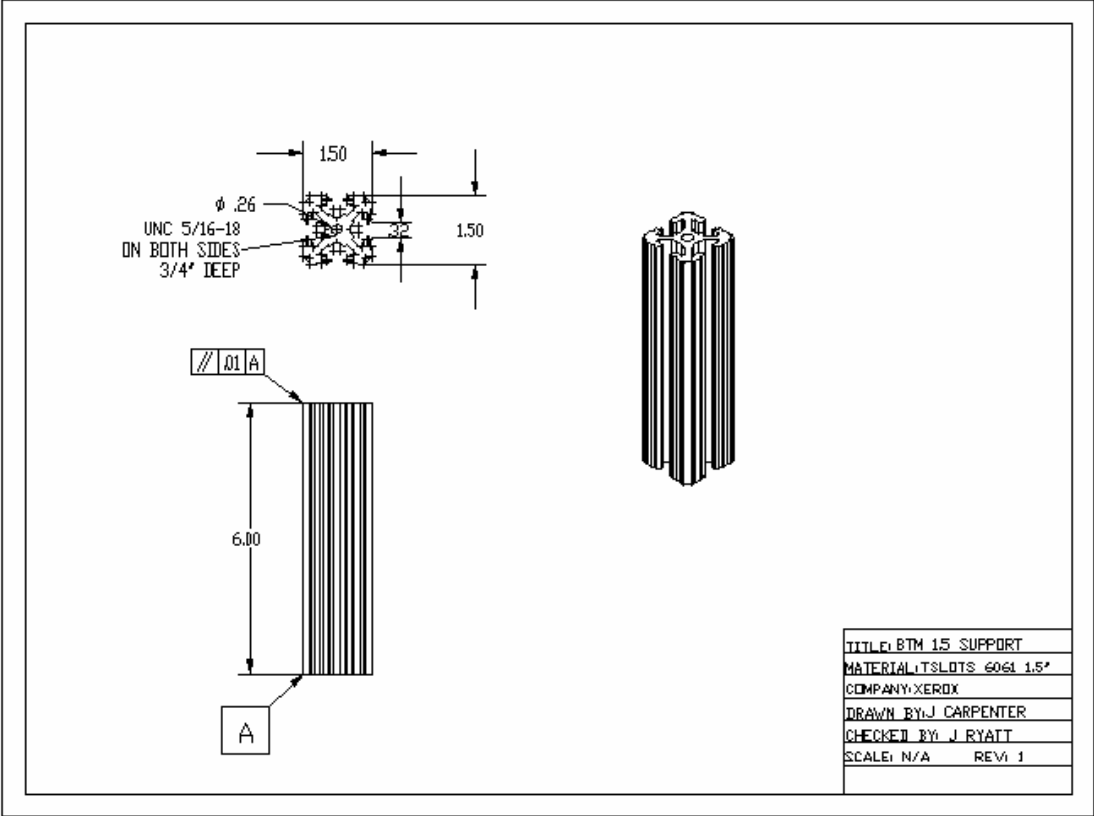


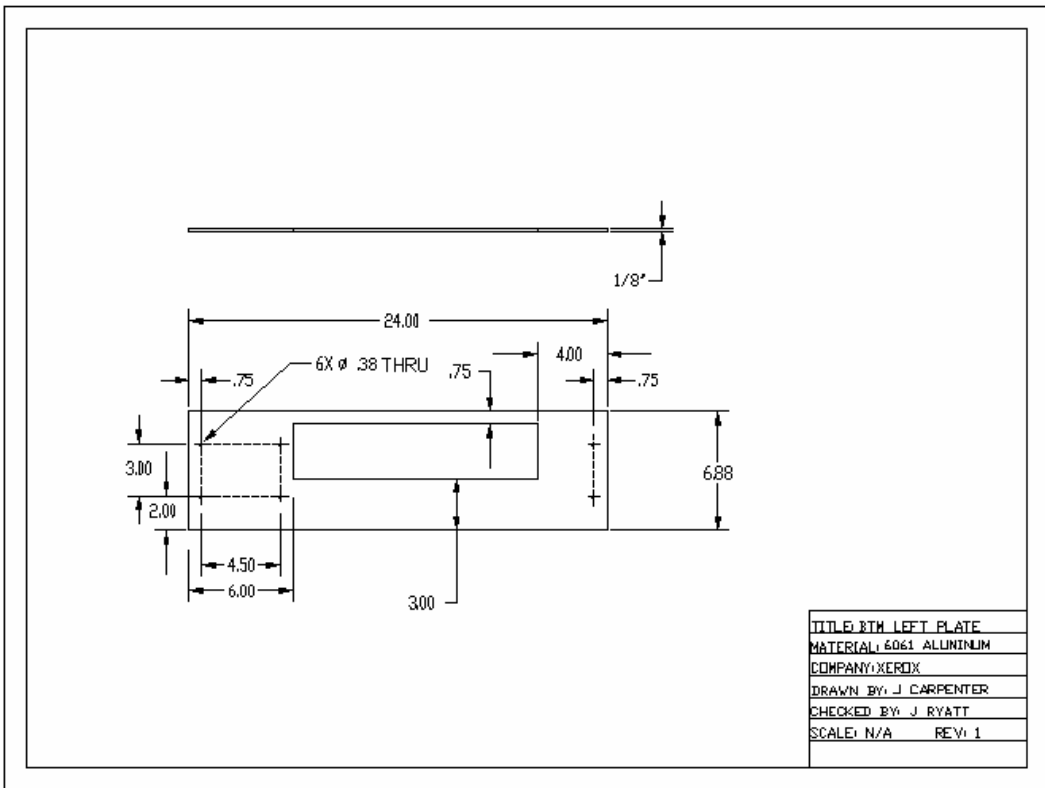
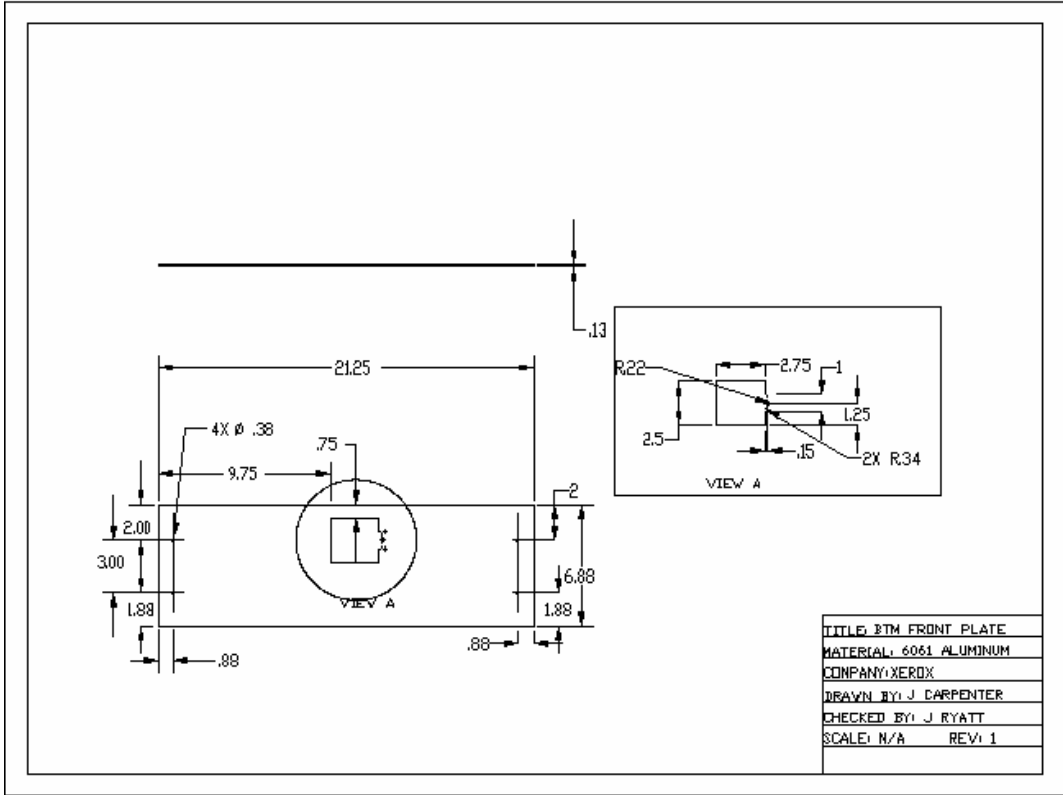


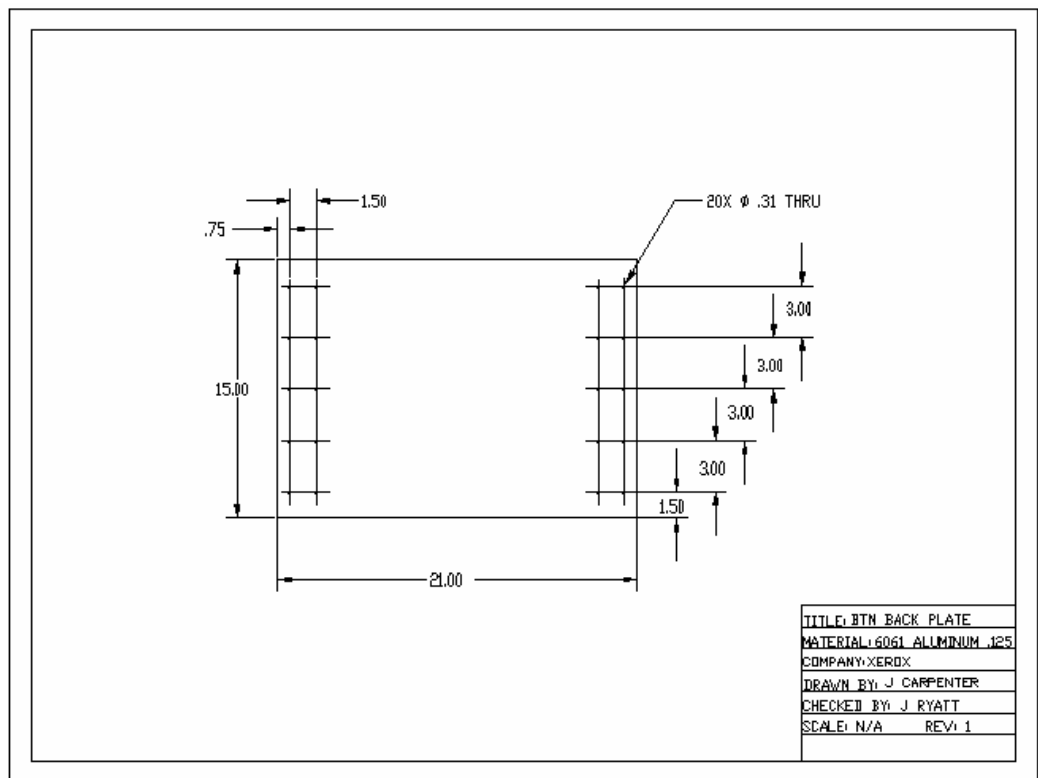
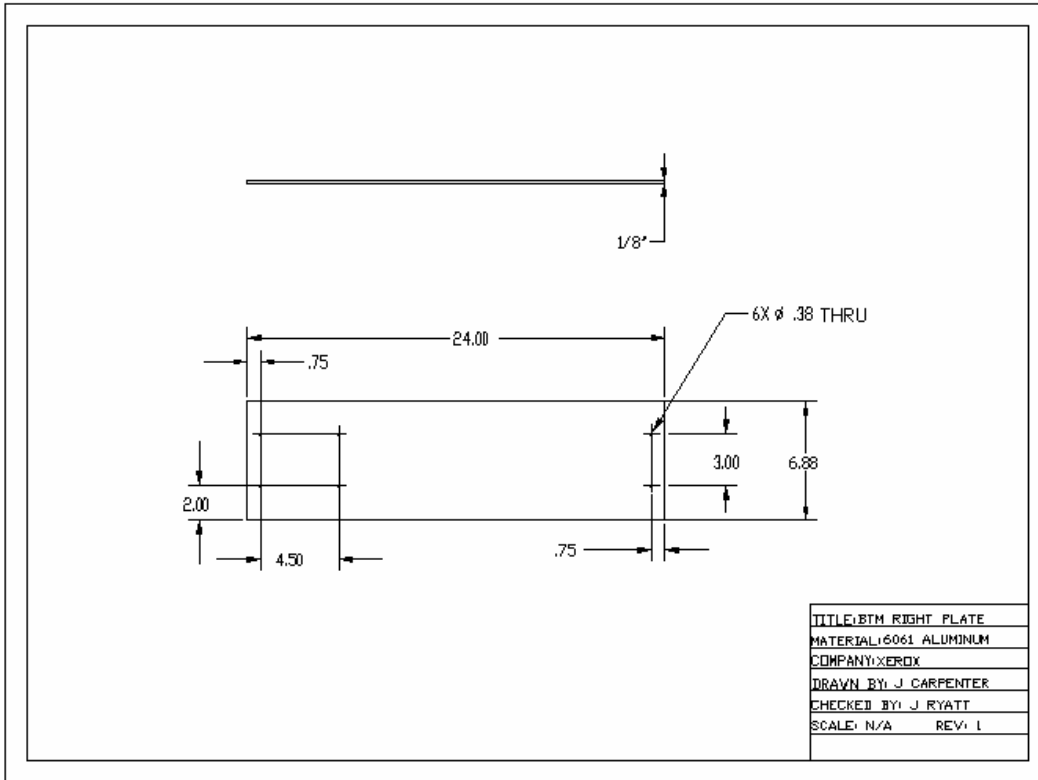


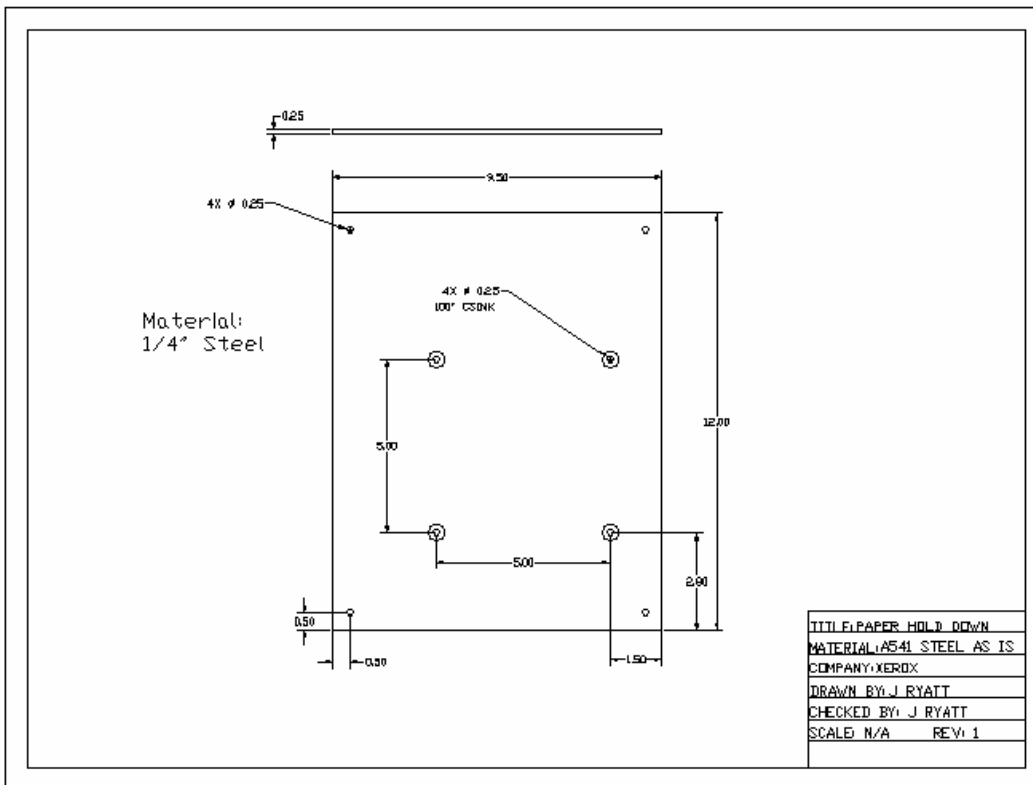
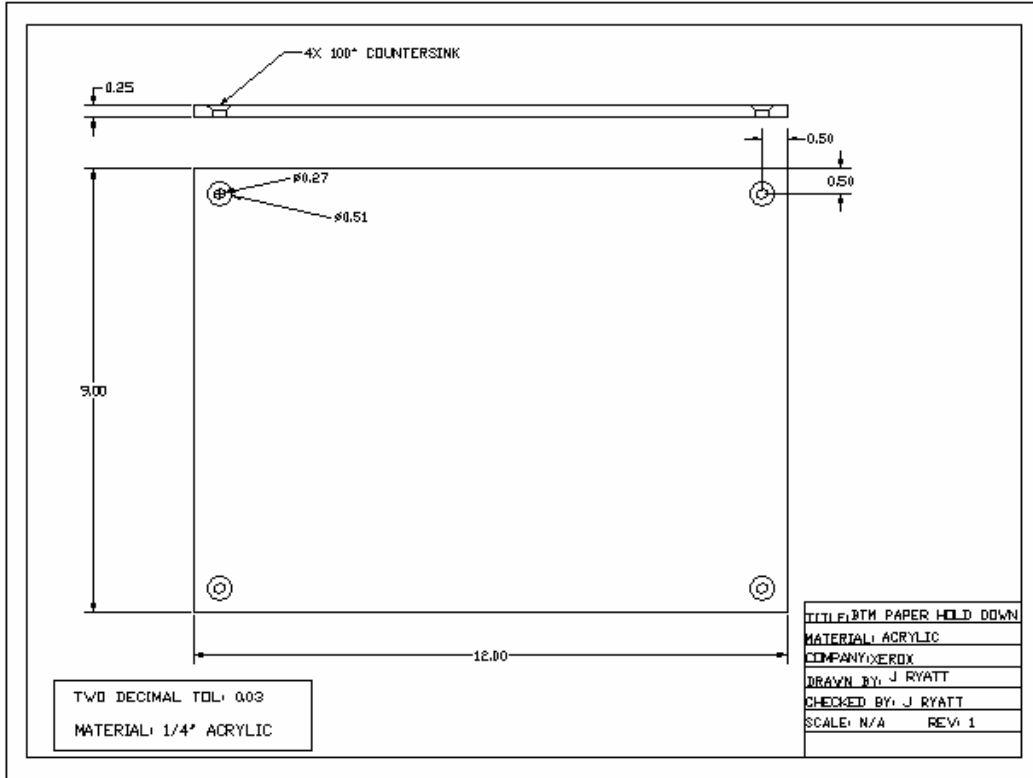


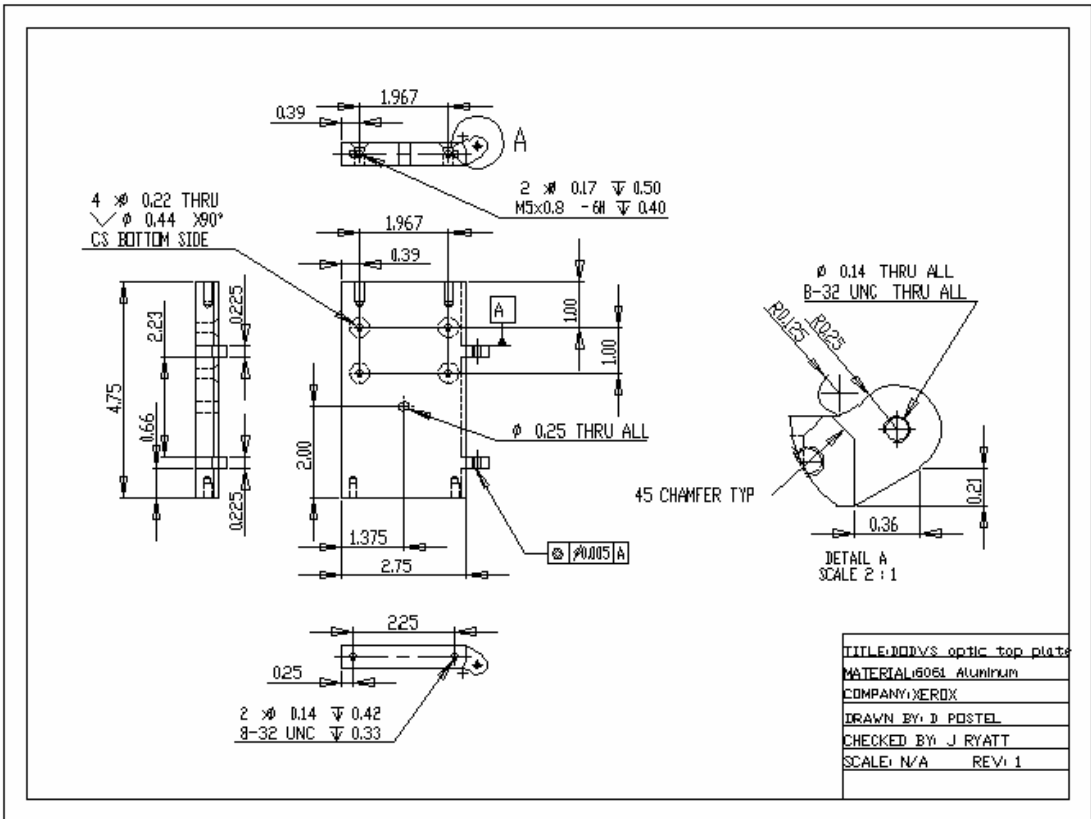
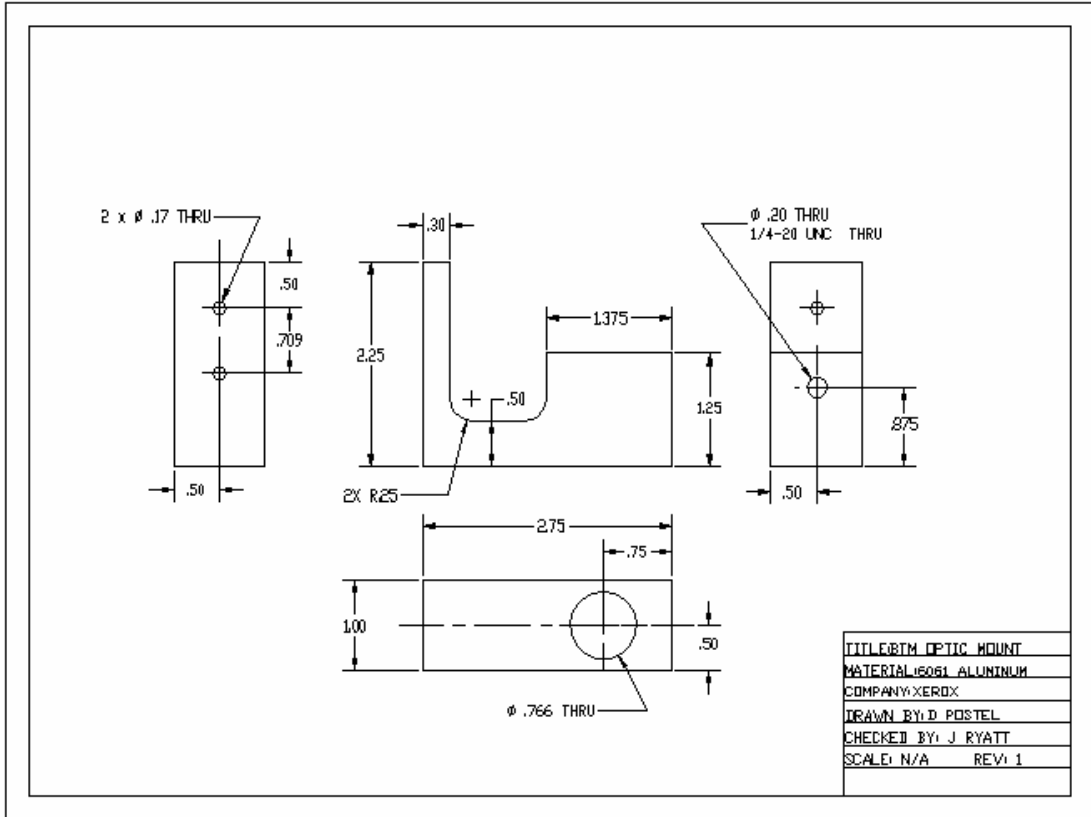


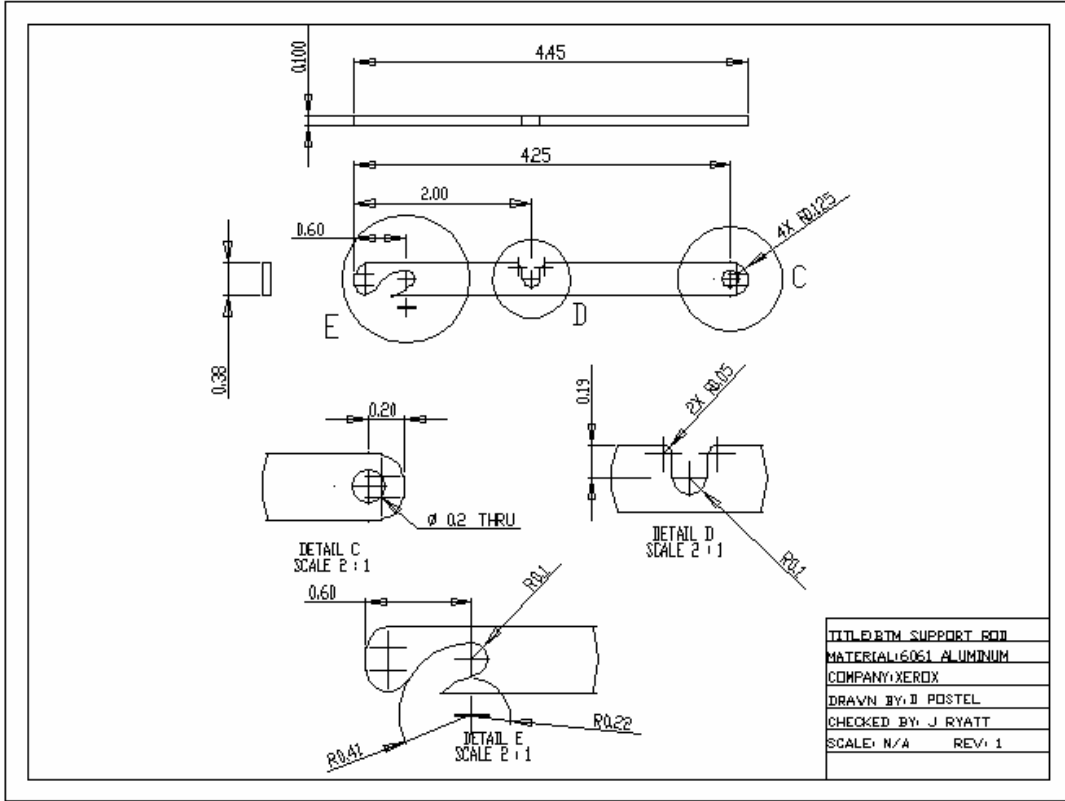




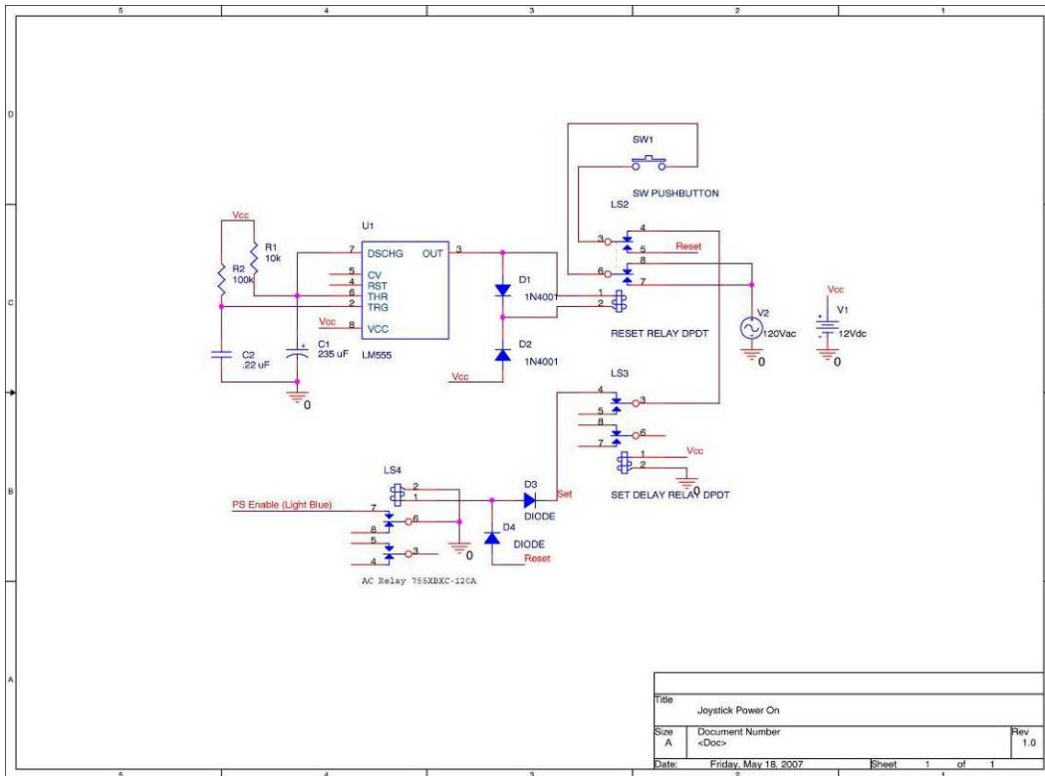








Circuit Diagrams





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