

An experimental set-up for simulating rotation of the brain in traffic accidents

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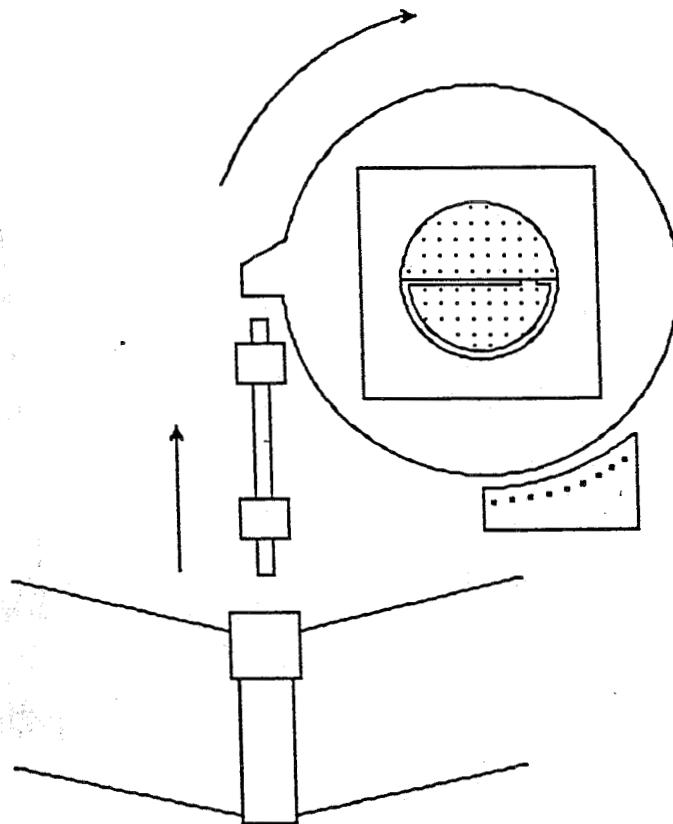
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**An experimental set-up for
simulating rotation of the
brain in traffic accidents**

Hans Cappon

R-033 /nr 95.177

Training period report

Göteborg, November 1995

**“Murphy lives in Sweden
and he doesn't like Dutch”**

Summary

The causes of intracranial injuries in traffic accidents are still not very well understood. These injuries might be caused by displacements of the brain relative to the skull. Rotational accelerations of the head are thought to be an important cause of these relative displacements.

To simulate the behaviour of the intracranial structures during rotation of the head an experimental set-up was made and tested. The set-up consisted of a pendulum hitting a turntable with a cranial model attached to it, causing rotational acceleration of the model. Accelerometers were used to measure the accelerations in the pendulum and on the turntable.

The model consisted of a perspex vessel containing silicone gel. Markers were placed in the gel to follow the movements of the gel. The displacements of the markers in the model were recorded by a high-speed camera. The kinematics of the gel were derived from the marker displacements.

LabVIEW 2 was used for programming the initialization of the experiment and for obtaining the data from the accelerometers.

Tests have shown that the experimental set-up works properly. These tests included testing the reproducibility of the accelerations and checking the accuracy of the acquired data. The presented experimental set-up will be used in future experiments to obtain insight in the effects of the intracranial structures on the kinematics inside the head.

Contents

Summary	1
Contents	2
1 Introduction	3
2 The model of the cranium	4
2.1 The perspex vessel.....	4
2.2 The gel.....	6
2.3 The model.....	6
3 The experimental set-up	8
3.1 The crash simulation.....	8
3.2 Data recording.....	10
3.2.1 accelerometers.....	10
3.2.2 high-speed film.....	11
4 Computerprogramming	12
4.1 Hardware.....	12
4.2 Software.....	12
5 Reproducibility and accuracy	14
5.1 Reproducibility.....	14
5.2 Accuracy.....	18
6 Conclusions and recommendations	19
6.1 Conclusions.....	19
6.2 Recommendations.....	20
References	21
Acknowledgements	22
Appendix A	
Equipment.....	23
Appendix B	
Set-up procedures.....	24
Appendix C	
LabVIEW as set-up controller.....	26
Appendix D	
Laugh behind my back.....	50

1 Introduction

The human brain is one of the more vital structures in the human body. When the brain is damaged, which often happens in accidents, a great part of the functioning in the body might be distorted. In the worst case the damage can cause death. The mechanisms causing injury to the brain and its connective tissue are not well known, but it looks like the damage is caused by movements of the brain relative to the skull and by relative movements inside the brain.

In a car collision the head usually rotates, with the axis of rotation somewhere down the cervical spine. This rotation can be divided in a rotational movement of the head around its centre of gravity and a translational movement of the centre of gravity. Both movements are considered to be important causes for brain injuries. In this report, only the rotational movement around the centre of gravity of the head is considered

For the simulation of the rotational movement, an experimental set-up and a intracranial model were developed. This report describes the model and the set-up, as well as some important considerations that should not be overlooked when making such a set-up.

Since it is impossible to look inside the head during an accident, a transparent model representing the skull and the brain was made. This model is of course a simplified version of the head. The set-up was made in order to expose this model to rotational acceleration and to record the acceleration of the model and the movements and deformations of the brain relative to the skull.

2 The model of the cranium

In order to analyse the motions of the brain relative to the skull, a model of the cranium was made. The model was two dimensional and represented a parasagittal plane of the human cranium. The model consisted of a perspex vessel and a transparent gel representing the skull and the brain, respectively. Markers were placed in the gel in order to record the displacements within the gel. The aim of this model was to find out if modelling of Cerebro Spinal Fluid and the membranes covering the brain had a great influence on the displacements of the markers in the model. For this purpose the vessel was divided in two halves. One half contained a membrane and fluid, the other did not.

2.1 The perspex vessel

The cranium was modeled with a PMMA (perspex) cylinder. Perspex was chosen for visibility reasons and it is strong enough to simulate the skull. The vessel had to be high enough to make sure that the boundary conditions at the top and bottom did not effect the movement of the markers in the middle of the gel. The vessel used had dimensions as given in figure 2.1. It was divided in two halves. Each half represented the cranium, which is the part of the skull enclosing the brain. As the rotational movement was the same for both halves, the effect of differences in intracranial structures could be examined.

In reality the brain is able to move inside the skull, but this movement is restricted by the bridging veins crossing the space between the brain and the skull, and by the spinal cord. Apart from the veins, the subdural space is filled with Cerebro Spinal Fluid and connective tissue.

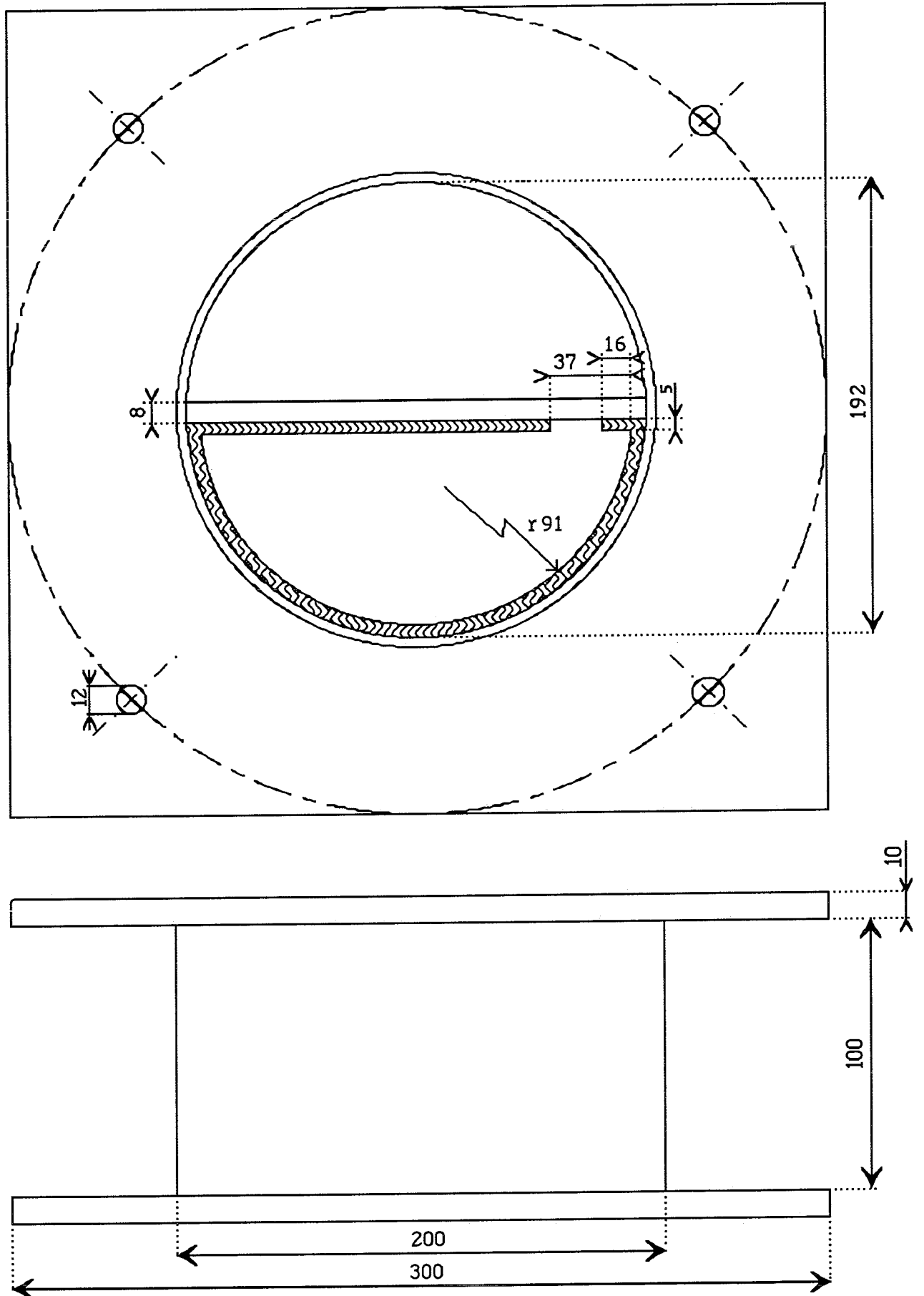


Figure 2.1 The perspex container

To check the effects of modeling the membranes and the layer of CSF covering the brain, in one half of the model the gel was separated from the vessel by a membrane and a layer of fluid, as can be seen in figure 2.1. Like the brain, the gel with the membrane was free to move inside the skull. The membrane created a certain space between the perspex and the gel and this space was filled with sunflower oil. Although CSF is a fluid which seems to have properties like water, the effect of the bloodvessels on the viscosity also needed to be taken into account. So the only reason that oil was used was that it is more viscous than water, thus representing the CSF with the bloodvessels.

2.2 The gel

According to J.E. Galford and J.H. McElhaney [3] brain tissue shows viscoelastic behaviour. Therefore, a viscoelastic gel was used to represent the brain. The gel also had to be transparent in order to see the markers clearly.

Originally, a water based gel was used [2]. The gel consisted of a superabsorbing powder, which could absorb many times its mass in water. For the experiments 1 mass unit of powder was added to 50 mass units of water. The thus obtained gel showed the desired behaviour. The main advantage of this gel was its low price, but it was difficult to get a clear and homogeneous gel.

Therefore, after several experiments with the water based gel without the desired results, another gel was given a try. This time Sylgard 527 Silicone dielectric gel was used. It is a two component gel and these components were mixed thoroughly in a 1 to 1 proportion. The mixture was then poured into the model. After 24 hours the gel was cured and ready to be used. Its viscosity at room temperature was then 330 mPas and its density 951 g/l.

2.3 The model

The vessel was first filled halfway with mixed gel. It was important to keep the membrane in its place, otherwise it would touch the vessel's wall, thus closing the space that was meant for the CSF substitute. As the uncured gel was very thin and ran into the space for the CSF substitute, a thin layer of gel was first poured in the half with the membrane and cured. After curing the rest of this half could be filled, because the first thin layer prevented the additional gel to run into the CSF space. The thin layer in the CSF space was removed afterwards.

After 24 hours a pattern of markers was put on the first half of gel. The pattern used is given in figure 2.2. Before the paper markers were put on the gel, they were saturated with one component of the gel to remove the air trapped inside the paper markers. The air in the paper would lead to air bubbles in the gel as soon as the second layer was added. These bubbles decrease the homogeneity and clarity of the gel.

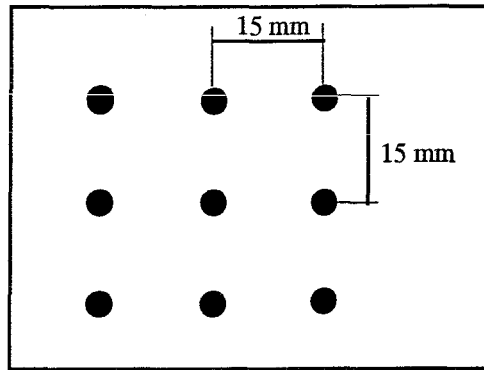


Figure 2.2 Marker pattern

To the first half of gel with the markers a second layer was added, which filled the entire vessel. While pouring, care was taken not to disturb the pattern of the markers. The top layers were cured and the CSF substitute, sunflower oil, was poured into the space between membrane and perspex. Finally, a very thin layer of sunflower oil was poured on top of the second layer of gel, in order to close the vessel without air being trapped inside, and the lid was fixed to the vessel. A picture of the completed model is given in figure 2.3.

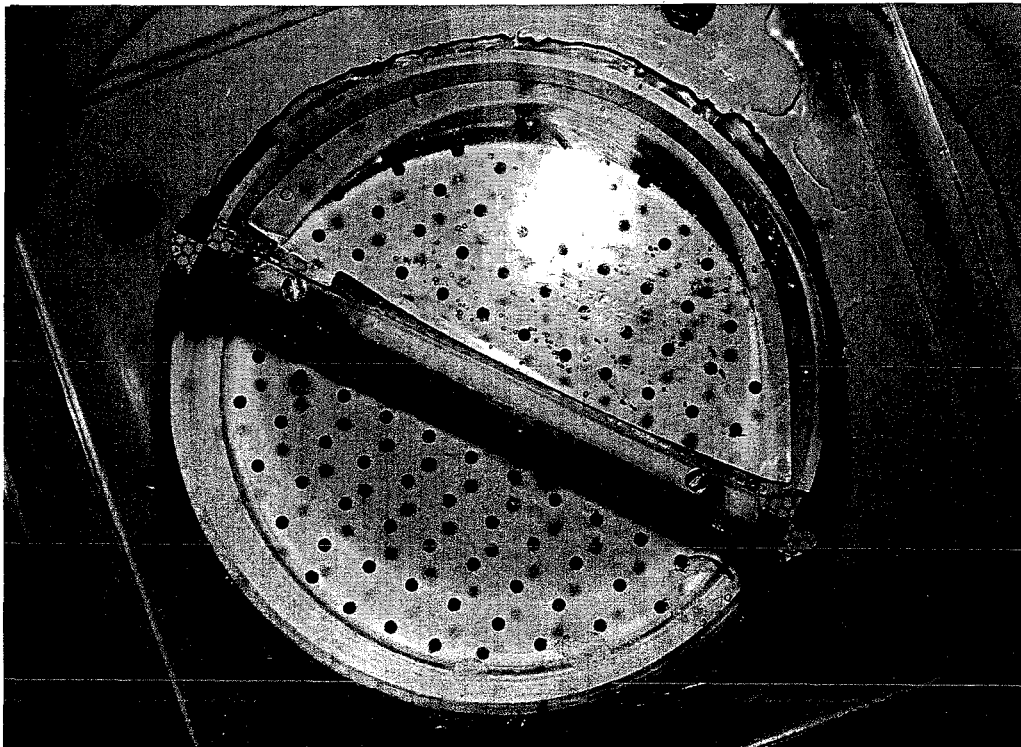


Figure 2.3 The model of the cranium

3 The experimental set-up

The experimental set-up contained two parts. The first was the crash simulating part, the second the data recording part. Both were controlled by a central computer. For the applied soft- and hardware see chapter 4.

3.1 The crash simulation

This part of the set-up (figure 3.1) consisted of three components, namely the pendulum, the turntable and the model.

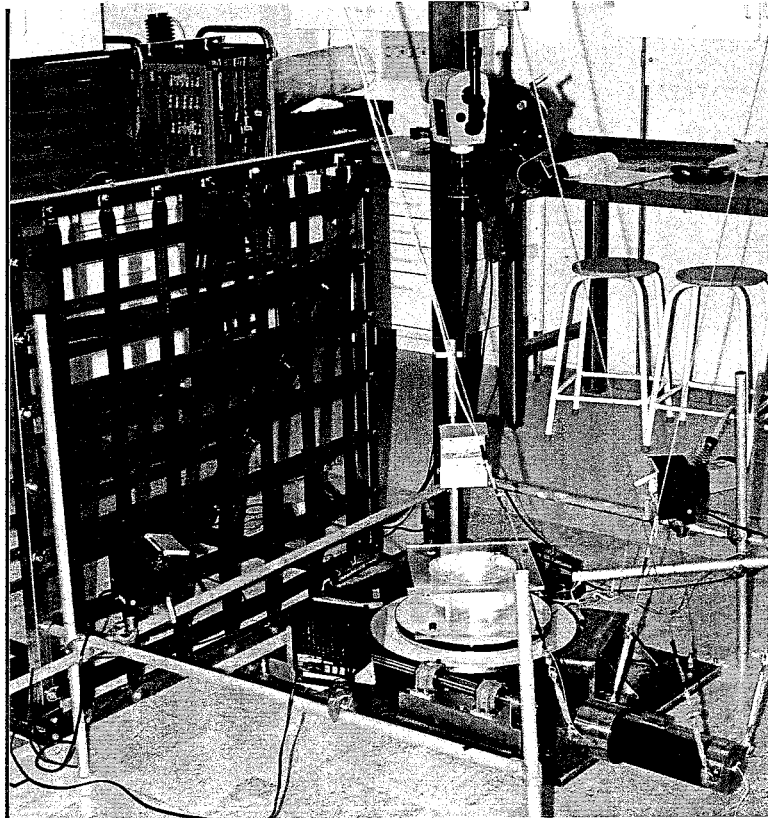


Figure 3.1 The crash simulation

The pendulum was a 22 kg steel cylinder (figure 3.2), which was attached to the 3.5 m high ceiling by 2 by 2 parallel steel wires. The wires kept the pendulum horizontal and stable during its fall. The pendulum was hauled by a rope, which was connected to a winch. The rope ran through a pulley attached to the ceiling about 4 m behind the pendulum.

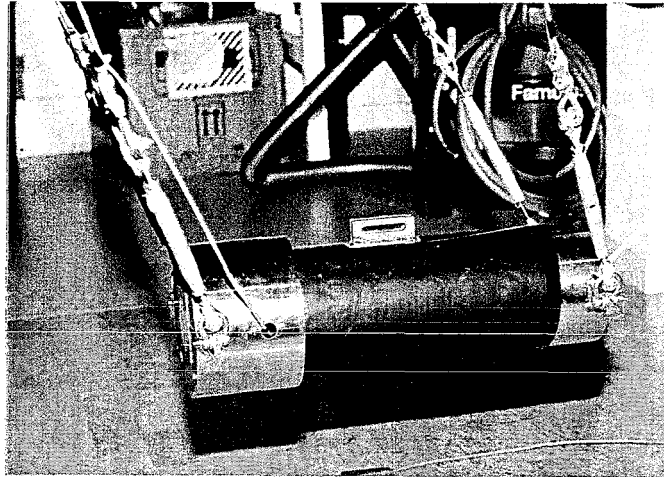


Figure 3.2 The pendulum

The pendulum had to be released with as little distortion as possible. For this purpose a seat belt fastening system was used which was activated by a pneumatic cylinder (figure 3.3). The valve for the pneumatic cylinder was activated by an electrical pulse generated by the computer. The valve worked at 12 volts and the computer gave 3.7 volts, so an additional converter had to be made for this purpose.

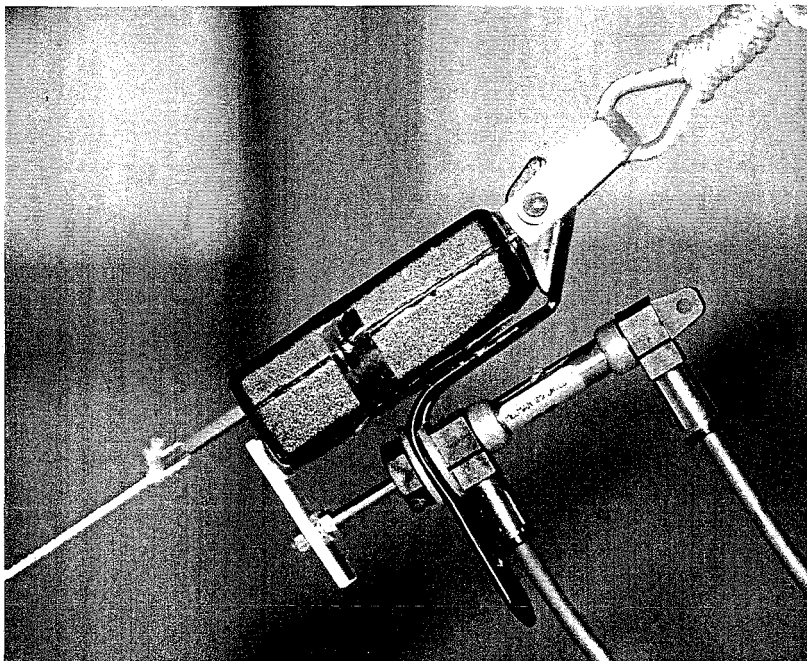


Figure 3.3 The release system

The turntable device was made of two circular steel plates bolted on top of each other. The lower plate was attached to a rear wheel hub of a Ford Escort. The shaft of the hub was fastened to a 100 kg steel plate, which was bolted to the floor. A projection was fixed to the lower plate of the turntable. This projection received the blow from the pendulum after which the turntable started rotating in a horizontal plane, so that gravity had no influence on the rotation. For accuracy reasons and to avoid loading of the

turntable outside its plane of rotation, a steel rod was used to transduce the blow from the pendulum to the turntable. The rod was guided by a bearing to obtain a horizontal, straight movement. Finally the same projection stopped the turntable from rotating when it encountered a series of nails placed straight up in a fissure through which the projection passed.

The model has already been described in chapter 2. The bolts attaching the model to the turntable were placed in the 4 holes in the model's lower perspex plate. So in summary the model received a blow directly from the pendulum if the interacting components, the rod and the steel turntable, were considered to be rigid and all the energy from the pendulum is transferred to the turntable. Of course loss of energy occurs, as the kinetic energy of the pendulum is not completely transferred to the rod and the kinetic energy of the rod is not completely transferred to the turntable. The padding material used between the pendulum and the rod also absorbs some energy. The purpose of this material is discussed in the next paragraph.

3.2 Data recording

The kinematics of the pendulum and the model are obtained in two ways. Two accelerometers measured the impact acceleration of the pendulum and the turntable, respectively. The acceleration data were acquired by a computer. The displacements of the markers in the gel were recorded on film by a high speed camera.

3.2.1 accelerometers

For the recording of the accelerations in the pendulum and on the turntable two piezoresistive accelerometers, Endevco model 7231C with options "S" and "T", were used with a range of 0-750 g and a frequency response up to 2000 Hz. Both accelerometers needed 10 V bridge excitation which was provided by the computer. This same computer amplified and recorded the output signals.

The accelerometer in the pendulum was placed in a small room made behind the spot where the pendulum struck the rod. To avoid metal to metal contact, resulting in high frequencies and corresponding high accelerations in the pendulum, padding material was placed between the pendulum and the rod. Without the padding the short pulse contact between the two steel objects would destroy the accelerometer. For the same reason a 0.86 cm high piece of copper pipe was placed between the padding and the rod when the pendulum was hauled higher than 30 cm.

A second accelerometer was glued on a small rubber mat on the turntable. The rubber prevented the distorting response of the accelerometer to the eigenfrequencies in the turntable plate, called "ringing". The accelerometer recorded tangential acceleration and its output was used to calculate the rotational acceleration.

3.2.2 high-speed film

The displacements of the markers were filmed by a high speed camera positioned straight above the model. To increase visibility of the markers, a layer of yellow paper was placed beneath the model on top of the turntable. After development of the film, the positions of the markers were digitized frame by frame and used to calculate the displacements and deformations in the gel. The kinematics of the model were derived from the digitized coordinates of markers on the vessel. The calculated accelerations were compared with the output given by the accelerometer on the turntable to check the accuracy of the digitization.

For filming at 1000 frames per second four light units were used. Each unit contained two 1000 Watt halogen bulbs. The units were placed at about 30 cm distance from the model and about 10 cm higher than the model. The aperture number f was set to 4, which was sufficient to produce a good film, although a smaller aperture number ($f=3$) would improve the film.

4 Computerprogramming

The data acquisition as well as the initiation of certain events, like camera start and pendulum release, was controlled by a computer. Computer control was necessary to attain the required precision in the time sequence of the events. For instance, when the camera had to run at a speed of 1000 frames per second it took 1.95 seconds for the camera to reach this speed. After these 1.95 seconds only 3 seconds were left for filming, as the film had a finite length. To make sure that the camera was at the right speed when the pendulum hit the rod, the time of the camera start and the release of the pendulum had to be exactly defined. It took 750 ms for the pendulum to fall from a height of 10 cm, so in that case the pendulum was released 1300 ms after the camera had started. Notice that the camera reached its speed 100 ms before the pendulum struck the rod ($1300 + 750 - 1950 = 100$). This margin was built in to make sure that the camera ran at the right speed. The data acquisition started 100 ms before the pendulum hit the rod, which was 650 ms after the release of the pendulum. Notice that data acquisition started after the camera had reached the right speed. The turntable rotated for about 1000 ms, so data acquisition usually took 1200 to 1500 ms in order to record acceleration of the start and stop of the turntable.

4.1 Hardware

The hardware consisted of a Macintosh IICI personal computer with a National Instruments NB-MIO-16L I/O board built in. The I/O board provided the functions which are needed for the experiments. Switches on this board were used to configure things like analog output range, analog input range and measuring mode. The measuring mode can be divided into differential or single-ended mode. The differential mode records the difference in voltage between the two output poles of the accelerometer, where the single-ended mode compares the output to ground. The differential mode was used, because the accelerometer output met the considerations specified in the NB-MIO-16 manual for use of this mode.

4.2 Software

One single software program was enough to run the complete experiment. In this case LabVIEW 2 took care of all events. Starting point for programming was an already existing program. There were a few things in this program that were still useful for this experimental set-up, like input channel scanning procedures and saving the measured

data. These two parts needed little adjustments to fit the needs. However, a lot of other parts were useless and had to be deleted or reprogrammed.

In the rest of this chapter the most important parts of the program called "pendulum" will be discussed, because a great deal of this project was spent on the development of this program. In appendix D the program "pendulum" is displayed.

Page 1 shows the front panel. In this panel the switches and values were set before running the program. The switches define whether certain events should take place or not. The values to be set were: input sample frequency, amount of samples per channel, sensitivity of the accelerometers, amount of channels scanned, gain and timing of the camera and pendulum start.

Windows 0,1 and 2 specified the settings needed for data acquisition. Windows 3 and its subroutines took care of the start of the camera and 1300 ms later the release of the pendulum (by configuring the used ports and writing the specified values to these ports, if they were activated automatically according to the front panel). Also the setting of the excitation voltage for both accelerometers was done in this window. The devices set in window 3 were reset in window 7 after data acquisition had occurred and the rotation of the turntable had stopped. Windows 5 and 6 contain the data acquisition routines that start 650 ms after the release of the pendulum. The output data obtained during 1350 ms are plotted in the front panel (window 9) and saved in a file (window 10) if specified in the frontpanel. Finally, window 11 returned possible errors to the monitor in the front panel.

5 Reproducibility and accuracy

After the set-up was made, it was important to find out if the measured accelerations were reproducible and if the recorded values were accurate enough to be used.

5.1 Reproducibility

To find out if the results were reproducible 4 series of test were performed. In these test peak accelerations and pulse duration were checked for reproducibility. The first series of 10 tests did not produce the desired results, because of two reasons:

1. The pendulum was connected to the release system by means of the steel part at the end of a seat belt. When the pendulum was released the connector hit the pendulum and this metal to metal contact was the cause of lots of noise in the signal. Figure 5.1 gives a good example of this distortion. After 740 ms the pendulum actually hits the rod. The peaks before that time were caused by the metal seat belt part hitting the pendulum. A plastic substitute took care of this problem.

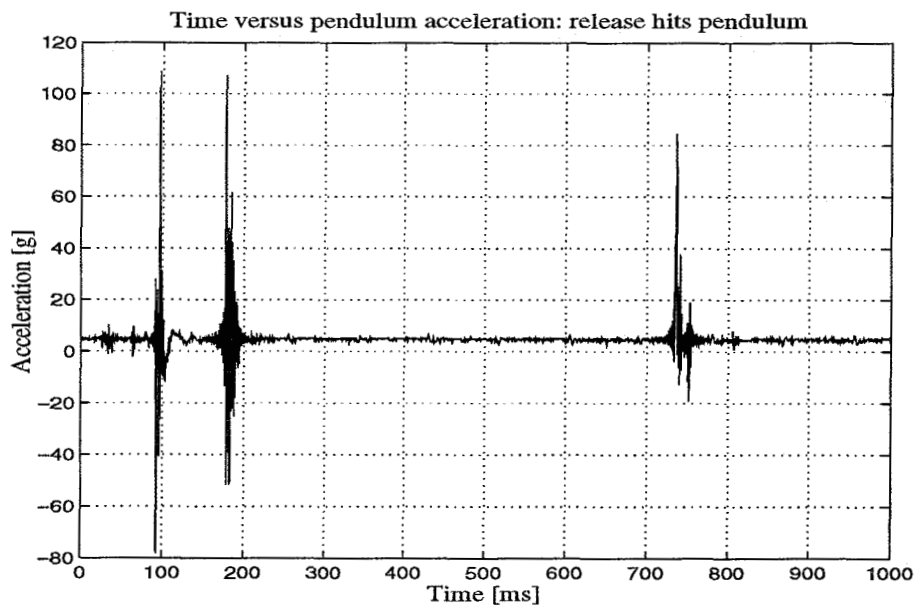


Figure 5.1 The steel connector to the release system hits the pendulum twice after releasing. At $t=740$ ms the pendulum hits the rod.

2. The rod which hit the projection of the turntable had to be accurately set against this projection before the pendulum was released. A very small gap between the rod and the projection split the deceleration peak of the pendulum in two smaller parts and caused high turntable accelerations due to severe short pulse blows. The turntable should be pushed away by the rod and not smashed away. An example of this smashing feature is given in figure 5.2 for a 2 mm gap and a pendulum height of 10 cm. Of course, there will always be a certain space left, but it should be as small as possible for more accurate results.

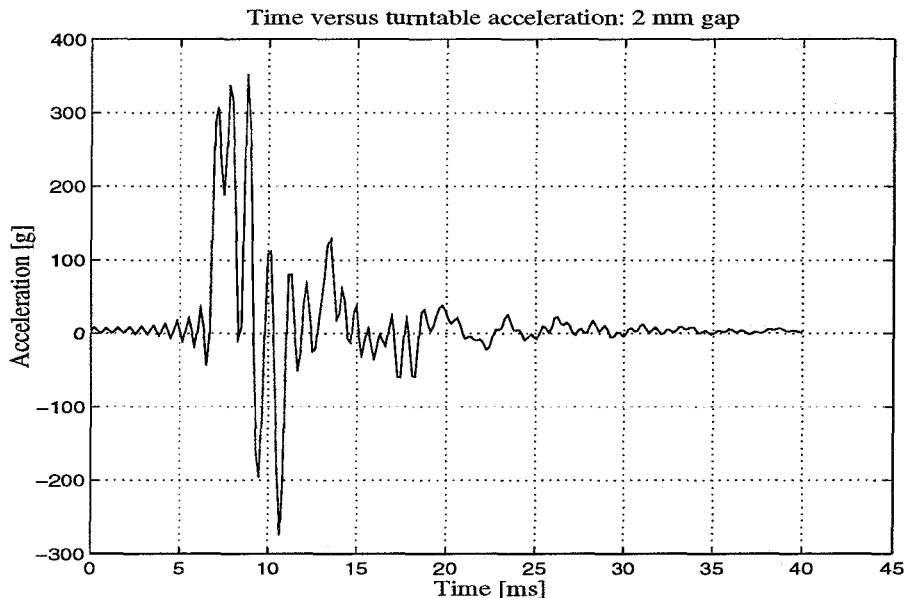


Figure 5.2 Between the rod and the turntable was a 2mm gap, which caused the severe blow to the turntable.

The second and third series were very accurately performed considering the second problem just mentioned. A small piece of tape was used to stick the projection of the turntable to the rod. This tape did not interfere with the transduced acceleration. A total of 13 measurements was made. The height from which the pendulum was dropped was again 10 cm and the sample frequency 6000 Hz. The computer was able to handle about 7000 samples per channel without overflow and data were acquired during 1000 ms. A sampling frequency of 6000 Hz resulted in taking 6000 samples per channel, which was within the capability range of the computer.

The fourth series consisted of 5 measurements. The pendulum height was 30 cm and the sampling frequency 4000 Hz. Typical responses for both pendulum and turntable for a height of 10cm are given in figure 5.3 and for a height of 30 cm in figure 5.4 . Please notice the differences in scaling.

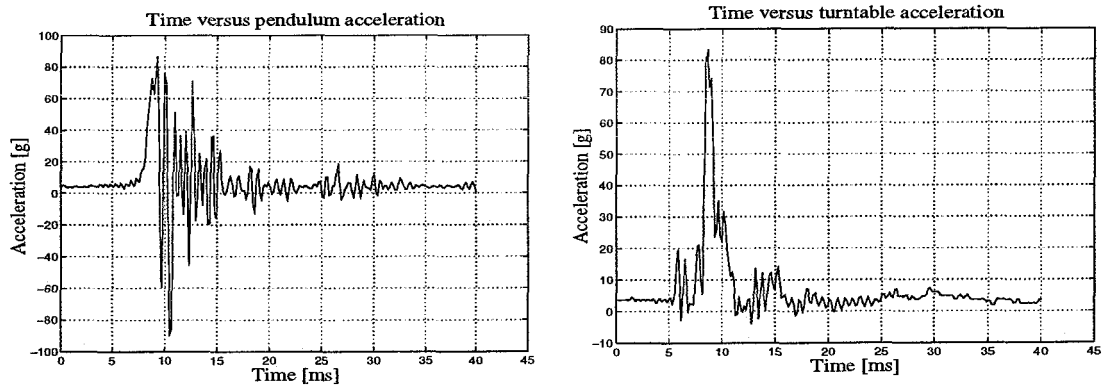


Figure 5.3 Example of the accelerations in a well performed simulation. The height of the pendulum was set to 10 cm.

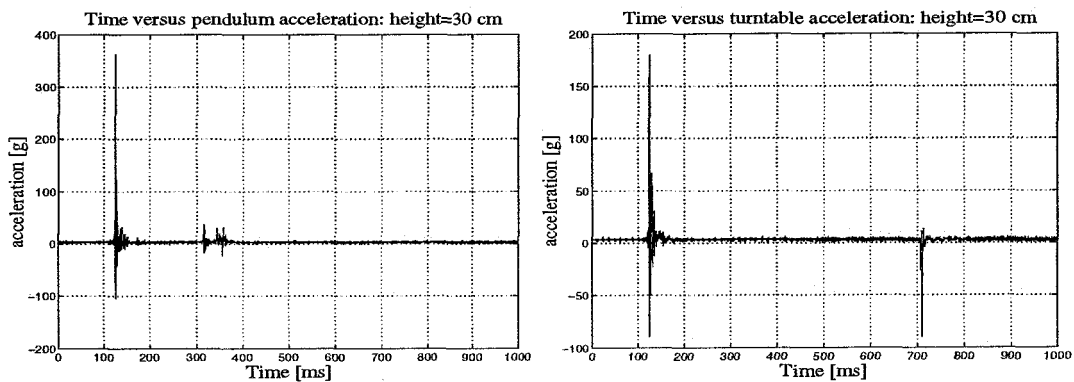


Figure 5.4 Example of the accelerations for a pendulum height of 30 cm. At $t=130$ ms the pendulum hits the rod and the turntable starts rotating. Rotation stops at $t=710$ ms.

The peak acceleration, its average and standard deviation are given in table 5.1. The average pulse duration for a height of 10 cm is given as well.

Table 5.1 Reproducibility

test number	acceleration [g] h=10cm		acceleration [g] h=30cm		
	pendulum	turntable	pendulum	turntable	turn. brake
1	155	78	248	153	-255
2	71	85	362	180	-90
3	171	81	236	231	-233
4	76	83	236	230	-51
5	167	87	194	227	-56
6	88	82			
7	170	114			
8	112	72			
9	153	100			
10	141	77			
11	60	101			
12	157	81			
13	137	103			
$\mu = \sum x/n$	127	88	249	204	137
Student sd.	40.5	12.4	67.2	35.7	99.1
pulse [ms]	3.5	4.5			

The reproducibility of the acceleration of the turntable, when it starts rotating, was fairly good. With a pendulum height of 10 cm, the accelerations above 100 g spoil the statistics. These accelerations could have been caused by little variation in the gap between rod and turntable, which was inevitable, unfortunately. For a pendulum height of 30 cm, some turntable accelerations were too small. The cause of this might have been that in every test the padding material between pendulum and rod was renewed, because it had simply been torn apart by the blow. It is very likely that the tearing of the padding was not the same in each test.

The braking of the turntable seems to be badly reproducible. Taking into account that one nail in this brake sustained several blows before breaking, these results can be expected. The deformation of the nail is different every time. Removing the nail after each test was an impossible job, because of the strange deformations. This means that little can be said about the brake.

It will be clear that the acceleration of the pendulum was not really reproducible, as eigenfrequencies in the pendulum had a great influence on the accelerations.

5.2 Accuracy

The accuracy of the acceleration measurement was determined. Amplification and sampling frequency of the computer were considered. It was not possible to check the accuracy of the accelerometer. Since they were new, they were considered to be well calibrated after production. The output voltage for 1 g was so small (0.2 mV) that it was impossible to measure accurately and the noise in the voltmeter was greater than the accelerometer output.

To test the accuracy of the computer, a harmonic signal was entered, amplified and sampled at 4000 Hz. The amplitude of the signal was set to 1 V by manually adjusting the voltage of the power source and monitoring the signal on an oscilloscope. The input frequency was 50 Hz. The result of this test is given in figure 5.5. It is clear that the 50 Hz is very well reproduced and that the accuracy of the amplitude was also reasonably good. The inaccuracy in amplitude was more likely due to an inaccurate setting of the amplitude at the source than an inaccurate measurement, because the manual setting and the oscilloscope both introduce a certain mistake.

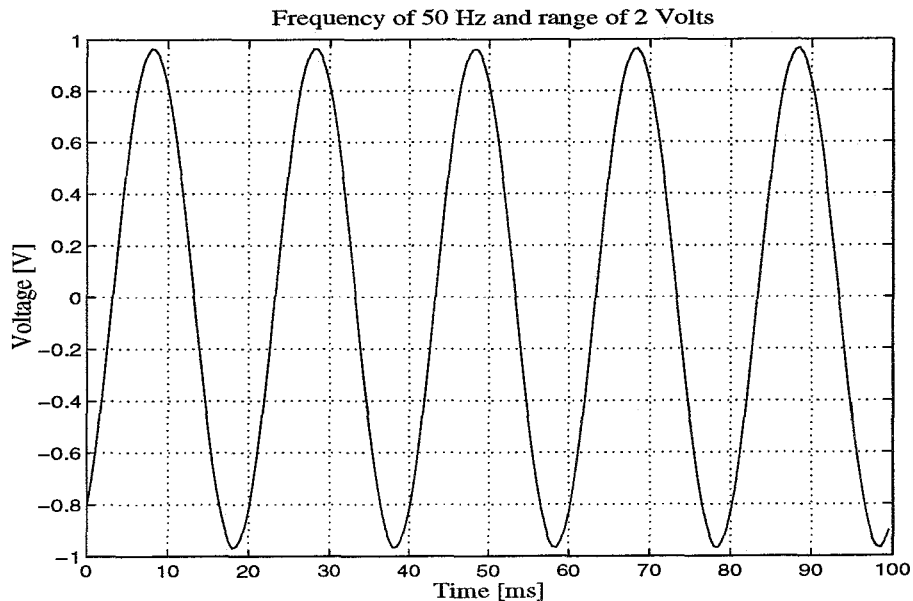


Figure 5.5 Sampling a 50 Hz and 1 V amplitude signal to check the accuracy of measurements

The timing of events in LabVIEW was also very good. The delays specified in the program were accurate enough to start the events like pendulum release and camera start at the right time.

6 Conclusions and recommendations

6.1 Conclusions

In general, the experimental set-up works properly. The results are accurate and reproducible. Certain aspects, however, can influence these results considerably.

For instance, it is very important to accurately set the rod against the projection of the turntable. A small gap causes major accelerations in the turntable, which can destroy the accelerometer. When the rod is accurately set, the turntable acceleration is well reproducible. The deceleration caused by the brake is not reproducible since the nails in the brake do not always deform in the same way. The rubber glued between the turntable and its accelerometer prevents the accelerometer from responding to the eigenfrequencies of the turntable, the so-called ringing.

Further, padding material between the pendulum and the rod hitting the turntable was needed to avoid the high frequencies and accelerations that occur in metal to metal contact. When higher accelerations are used a piece of copper should be added to increase the pulse duration and prevent high accelerations at high frequencies. Accelerations in the pendulum are badly reproducible, as eigenfrequencies in the pendulum highly influence the signal.

An electrically activated pneumatic cylinder activating a seat belt fastening system is a very good way of timing the release of the pendulum.

Sylgard 527 silicone gel is a good brain substitute, as far as viscoelasticity, clarity and homogeneity are concerned. The gel made from superabsorbing powder is also a useful brain substitute, although homogeneity and clarity are very hard to establish.

LabVIEW 2 together with the NB/MIO/16L I/O board is capable of running the set-up in terms of starting the camera, releasing the pendulum, amplifying and acquiring the data. Accuracy of LabVIEW's timing and data acquisition is good.

6.2 Recommendations

For further development of the set-up and the model in the future a few recommendations can be given. The current turntable is made of steel. To produce the desired accelerations in this turntable severe blows are needed due to the inertia of the plate. A lighter material for the turntable is therefore recommended, for instance aluminium. The lighter turntable will also reflect the real situation better, as the rotation of the human head needs less severe blows to reach a certain acceleration than the steel turntable.

When the pendulum will be hauled higher than is done so far, care must be taken when setting the rod against the projection of the turntable. An uncared setting of the rod is able to destroy an accelerometer when the pendulum is hauled just 20 cm.

For the recording of the displacements in the gel a high-speed video system is recommended. The desired frames can be selected and stored on video. If a test fails there is nothing lost yet. Some systems have the possibility to follow certain markers in time and registrate the location of the markers, so manually digitizing markers frame by frame is no longer needed. This digitizing is very time consuming and also causes more inaccurate results.

Since the brake of the turntable does not give reproducible decelerations, a different system is advised. Maybe it is possible to use a real restraint system to stop the rotational movement. The projection will encounter a seat belt instead of a series of nails. Another idea might be to use a spring-damper system, which is easier to model in a computer simulation of the tests. If more than one nail breaks in the current set-up the deceleration occurs in shocks.

To check if the material properties of the gel make a great difference for the displacements in the gel another gel with different properties or the same gel mixed in different proportions should be used. Using another kind of fluid to model CSF and another membrane might also give a different response to accelerations.

To visualize flow patterns in the CSF substitute, particles could be added to it. These particles should be visible on the film.

To increase visibility of the markers on high-speed film a darker kind of yellow paper must be used beneath the model. The yellow paper used in the experiments reflected too much light. Another, even better, advice is to make the lower perspex plate of the model of mat yellow plastic.

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God, first of all, for giving me the opportunity to come to this country, for giving me new friends and His comfort when things did not go very well. You are my best Friend!

Jack van Hoof, my supervisor, for the help he has given me. Thank you also for being a good friend.

Fons Sauren for the first arrangement you made for me to go to Sweden and for being the contact person at Eindhoven University of Technology.

The people in this department, like Mats A., Chantal, Adam, Sonja, Ingegerd and Dagmar for their friendship and happy faces every day.

Loes and my family for the support they have given me by letters, e-mail and telephone.

Lennart Malm for all the accurately made devices we needed for the experiments.

My housemates and friends at Olofshöjd for all the conversations in and around the kitchen.

Appendix A: Equipment

Computer: Macintosh IIci with a National Instruments NB/MIO/16L I/O board installed.

Software: National Instruments LabVIEW 2

Accelerometers: 2 Endevco piezoresistive accelerometers. Model 7231C-750 with options "S" ($\pm 3\%$ tolerance on sensitivity) and "T" (1% transverse sensitivity). Serial numbers APDK1 and AN377.

Camera: Stalex WS-2 16 mm high-speed camera with KERN Vario-Switar 12.5-100 mm lens.

Oscilloscope: Hitachi V-245

Function generator: Tektronix FG 501

Power supply (for 12 V DC): Mascot type 719

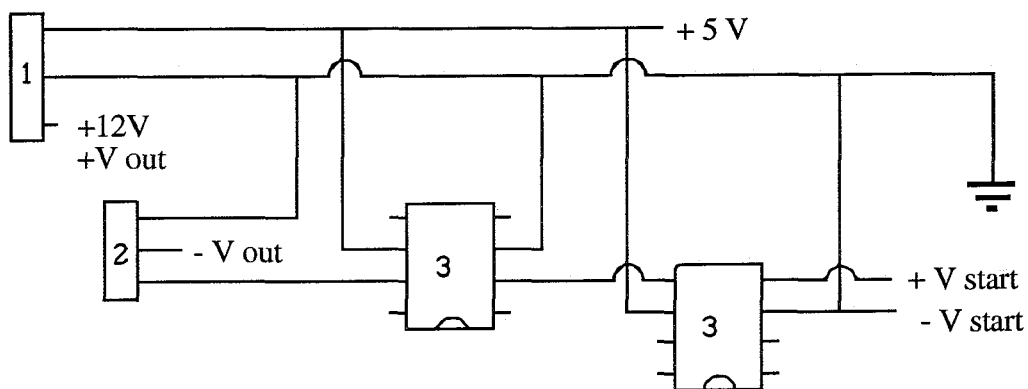
Electronic device :

The device displayed below sets an output voltage difference of 12 V to V_{out} , as soon as V_{start} receives a 3.7 V digital signal from the computer. The 12 V output opens the valve to the pneumatic system releasing the pendulum.

1= Voltage regulator: 78 S15 CV

2= Mosfet: BUZ 11

3= Double power mosfet driver: ICL 7667 CPA



Appendix B: Set-up procedures

B1: Starting procedure for brainmodel set-up.

Check if all cables and wires are well connected.

Computer

Start the computer and select the program "pendulum".

Make sure that all the controls in the frontpanel are in the right position or contain the right data.

Run the program "test total" to make sure that the analog output and the digital output are zeroed.

Camera

Make sure the camera is focussed on the desired area and that it contains a film.

Switch the camera on.

Pendulum

Switch on the power source for the release system of the pendulum.

Connect the pendulum to the release mechanism: is it secured?

Haul the pendulum a little in order to set the turntable and rod into the right position.

Set the turntable in such a position that the rod will hit the projection of the turntable perpendicular.

Put the rod against the projection.

Apply pressure to the release mechanism of the pendulum.

Haul the pendulum to the desired height.

The set-up is now ready to run. Run VI "pendulum".

Safety check

Please check all the devices, which must bear high loads during the experiments every ten cycles. Make sure that nothing has broken down and that all screws and bolts are secured.

B2: Connections to the accelerometers.

The accelerometer **apdk1** is positioned inside the pendulum, the accelerometer **an377** on the turntable.

Both have 4 pins which are connected according to the picture below. Note that the used colors are different from the specification in the picture. The colors are as follows:

- Output +: green
- Output -: yellow
- Input +: red
- Input -: blue

The female Lemo1B connector is different for both channels. The configuration is given for both below, the number which is added between brackets is the pin number of the computer I/O board.

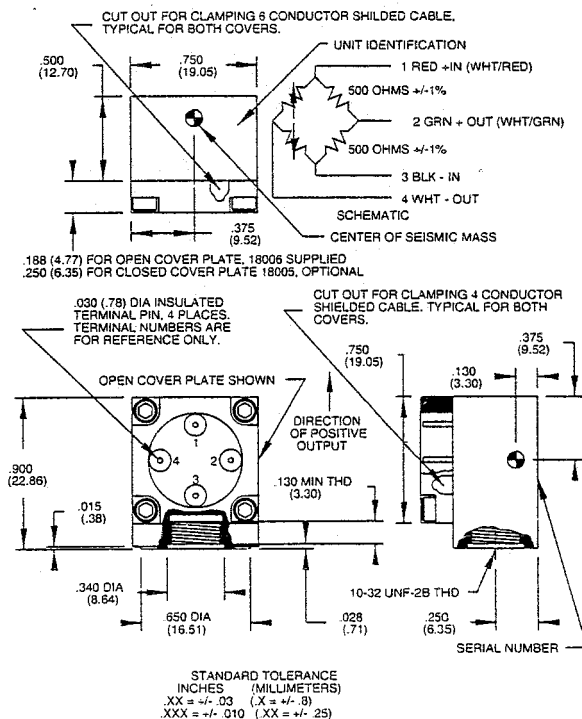
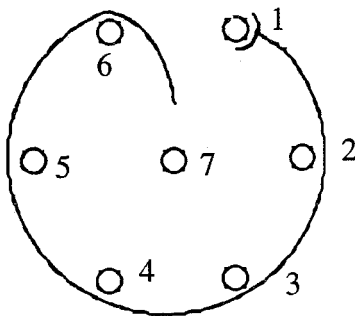
For apdk1:

- 1 Sense line +
- 2 Sense line - : yellow
- 3 Amp. input + : green (3)
- 4 Bridge exc.+ : pink (20)
- 5 Bridge exc.- : brown (23)
- 6 Amp. input - : white (4)
- 7 Ground : protection (1)

For an377:

- 1 -
- 2 -
- 3 Amp. input + : green (5)
- 4 Bridge exc. + : red (21)
- 5 Bridge exc. - : black (23)
- 6 Amp. input - : white (6)
- 7 Ground : protection (2)

LEMO 1B



Front Panel

BEFORE RUNNING THIS PROGRAM, THE OUTPUT VOLTAGES OF THE ANALOG AND DIGITAL OUTPUT MUST BE CHECKED. THESE VOLTAGES SHOULD ALL BE ZERO. IF NOT, RUN THE PROGRAM "TEST TOTAL" FIRST

STORAGE

- Save files
- Do not save

CAMERASTART

- Automatic
- Manual

PENDULUMSTART

- Automatic
- Manual

DECIMAL SIGN

- Dot (.)
- Comma (,)

MONITORING

DAQ_Clear: No data acquisition is in progress.
 DAQ_Config: No Error
 DAQ_Trigger: No Error
 SCAN_Setup: No Error
 SCAN_OP: No Error

CHANNELS USED FOR MEASUREMENT

2

INPUT SAMPLING-FREQUENCY (Hz)

4000

SAMPLES PER CHANNEL

5500

REAL SAMPLING FREQUENCY (Hz)

4000,00

CHANNEL + SENSITIVITY

0 1,963E-4

GAIN 1, 10, 100, 500

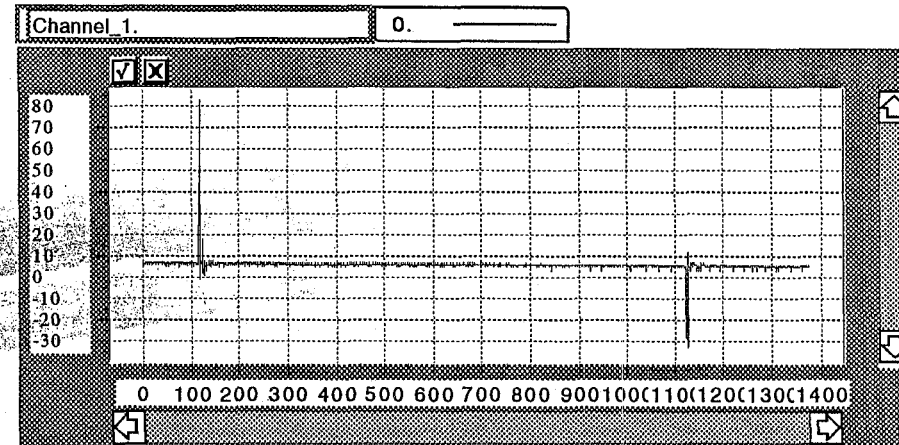
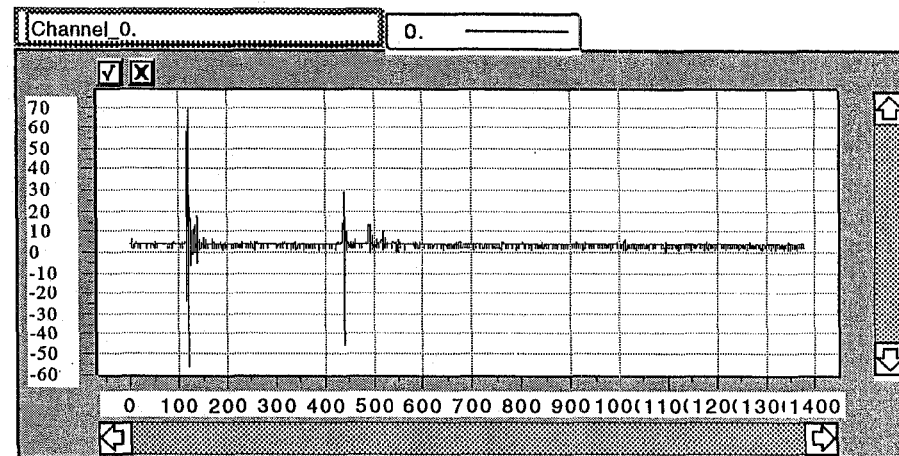
10

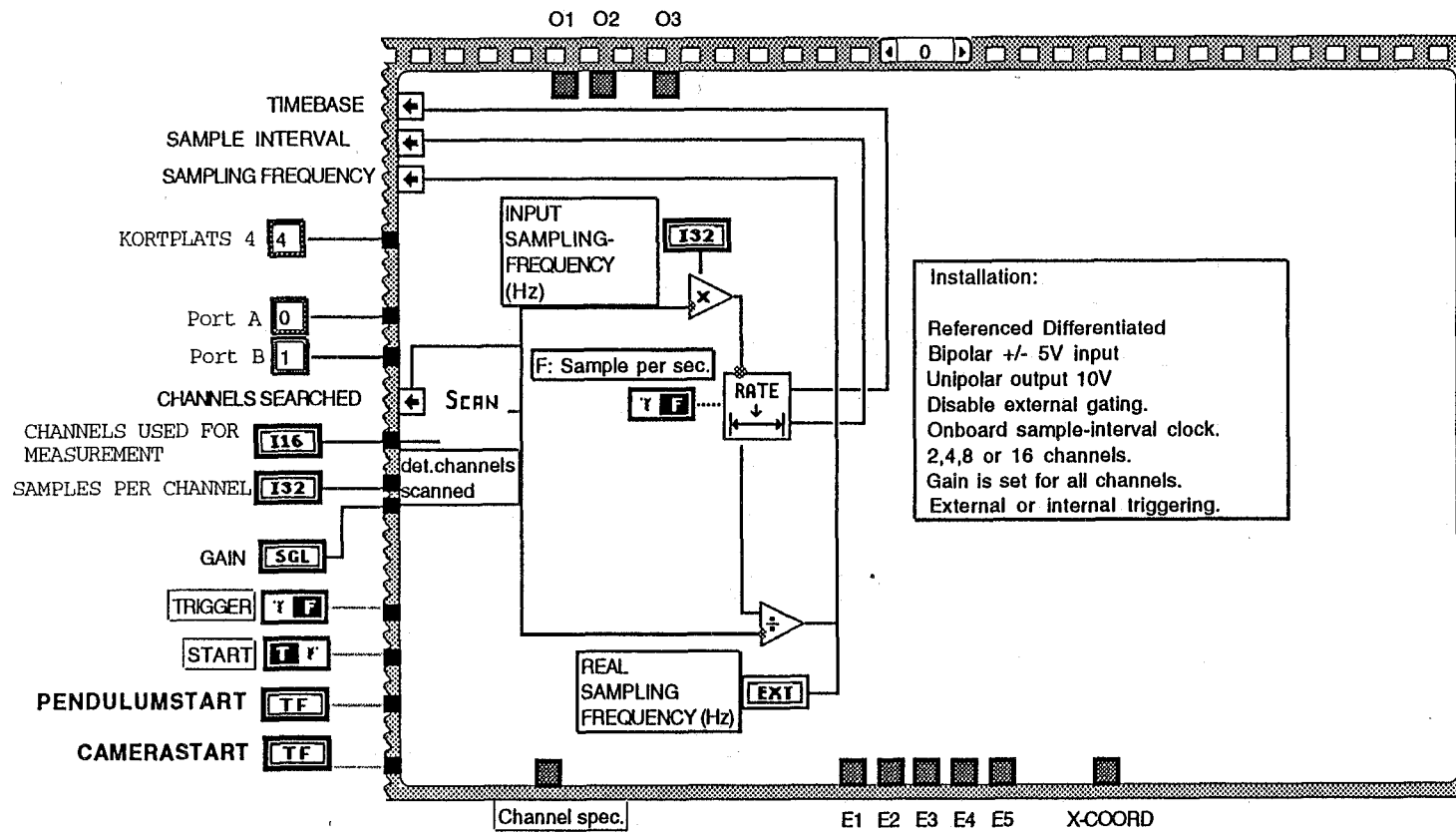
RELEASE OF PENDULUM AFTER CAMERASTART (ms)

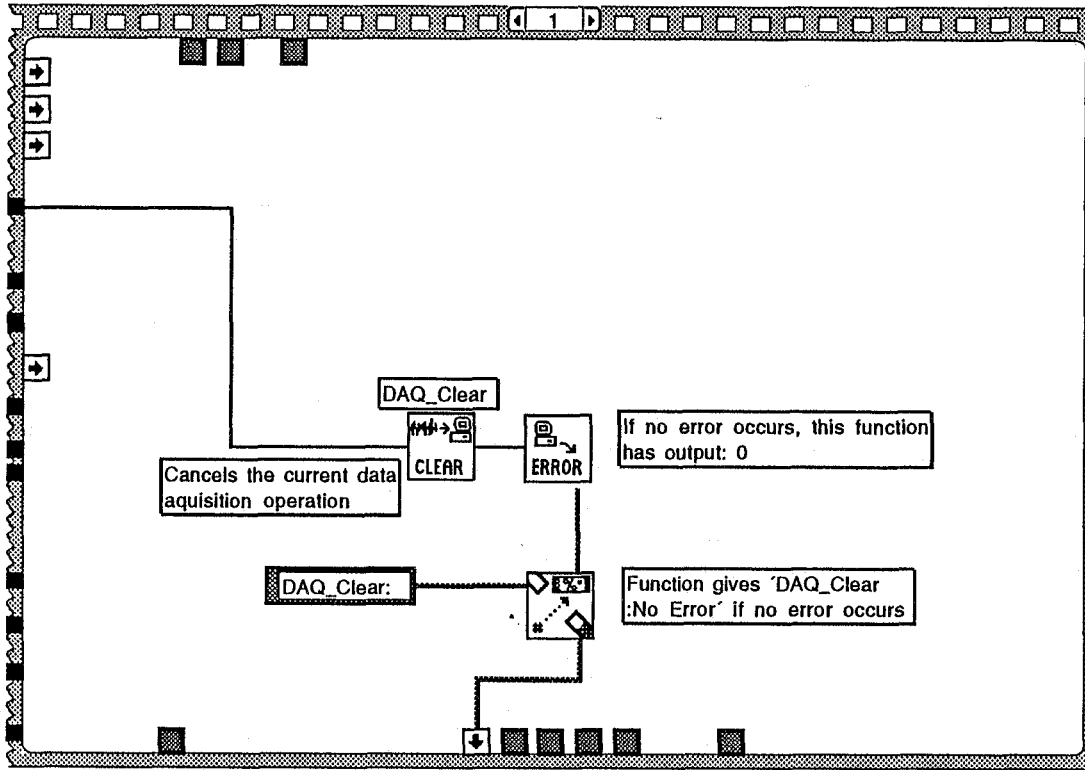
1300

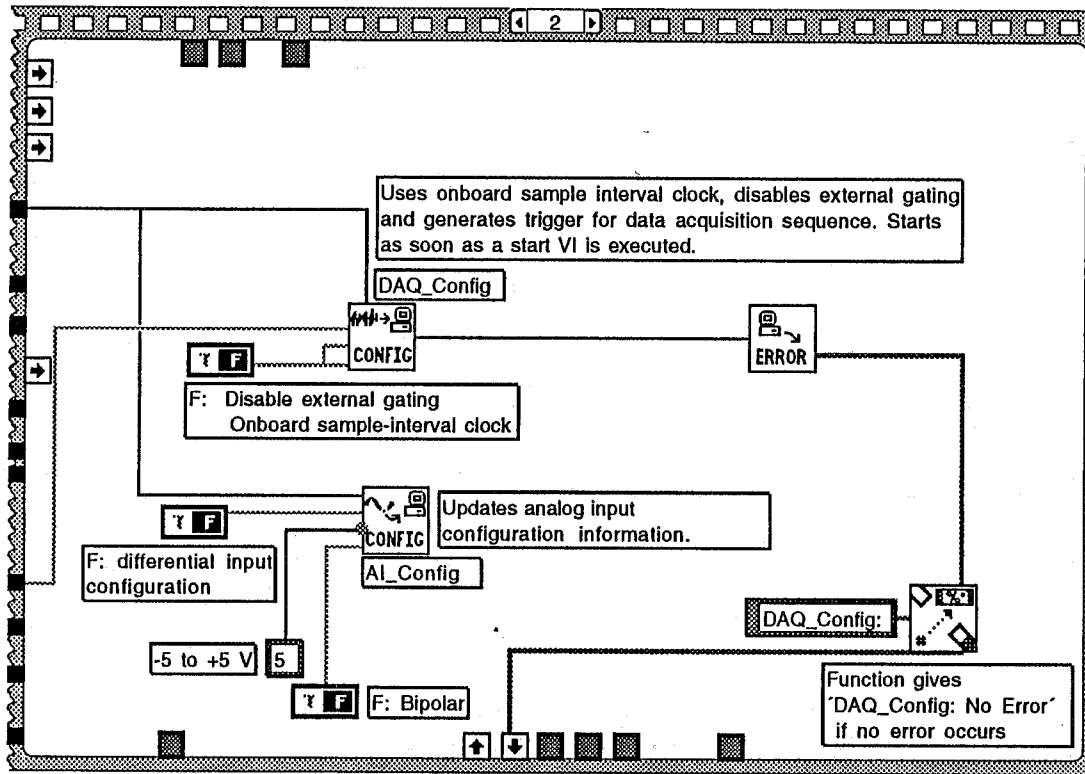
WAIT .ms AFTER RELEASE PENDULUM BEFORE START DATA ACQUISITION

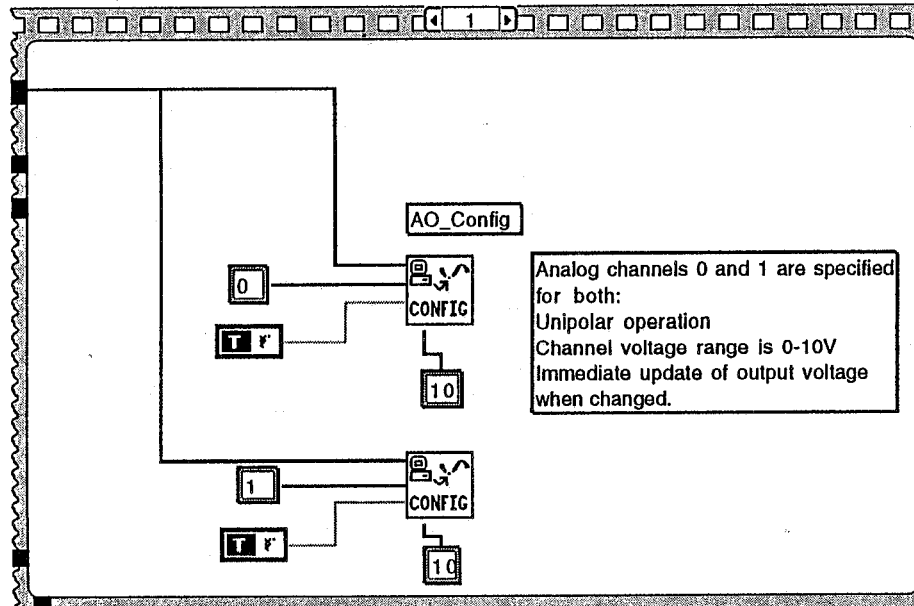
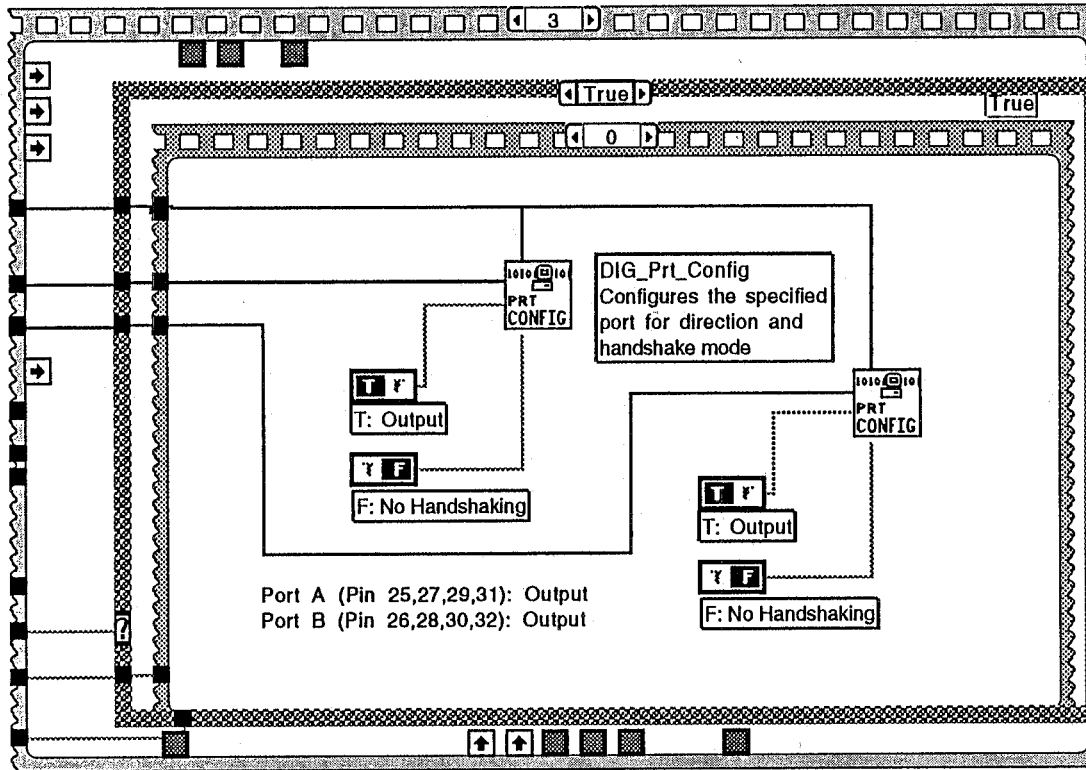
650

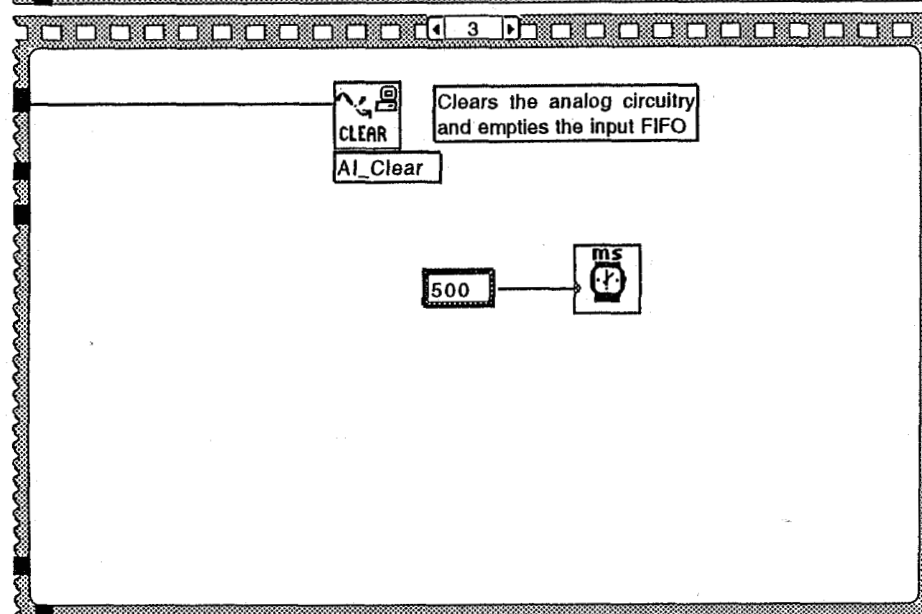
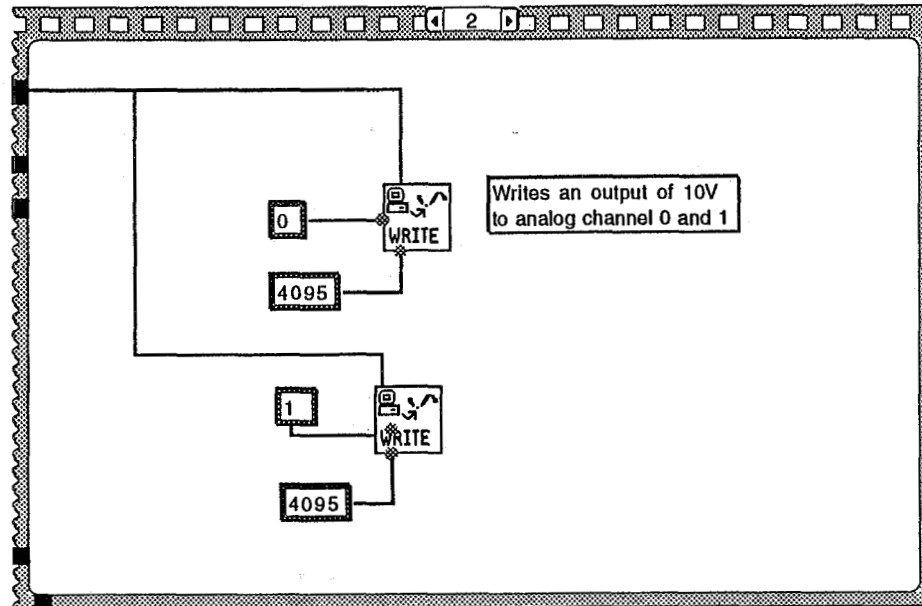


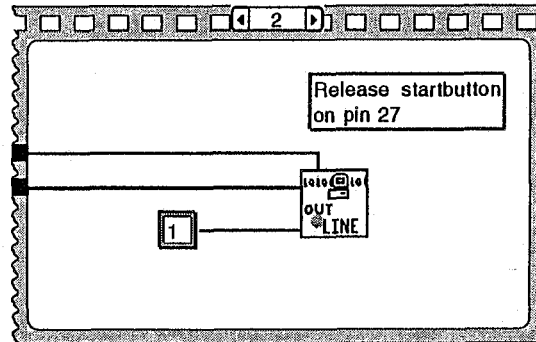
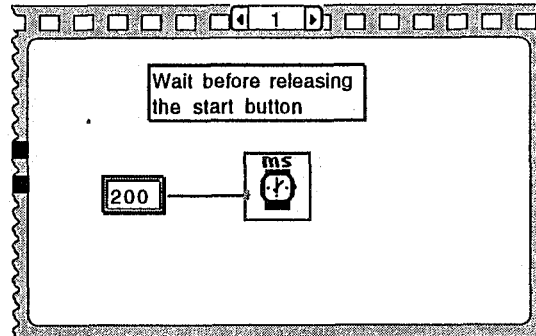
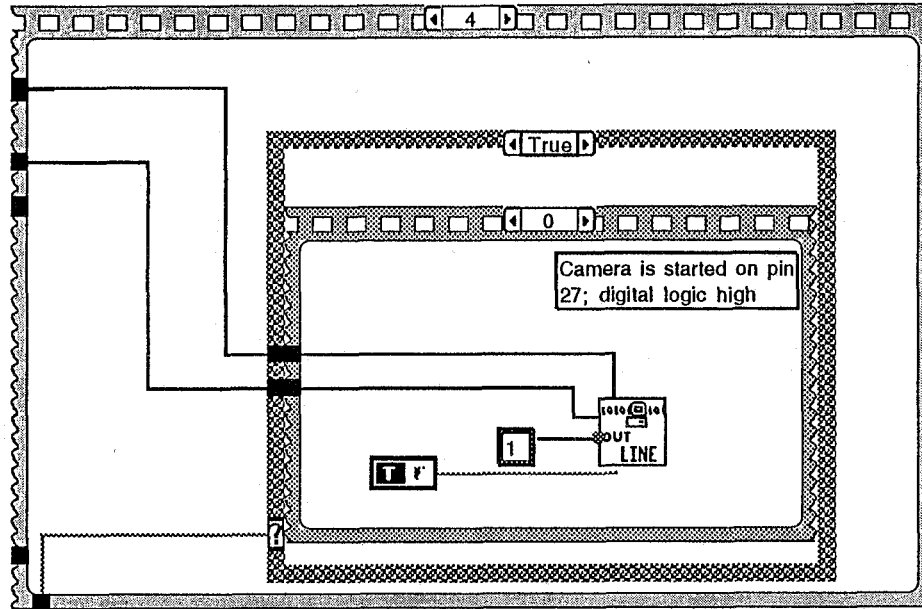


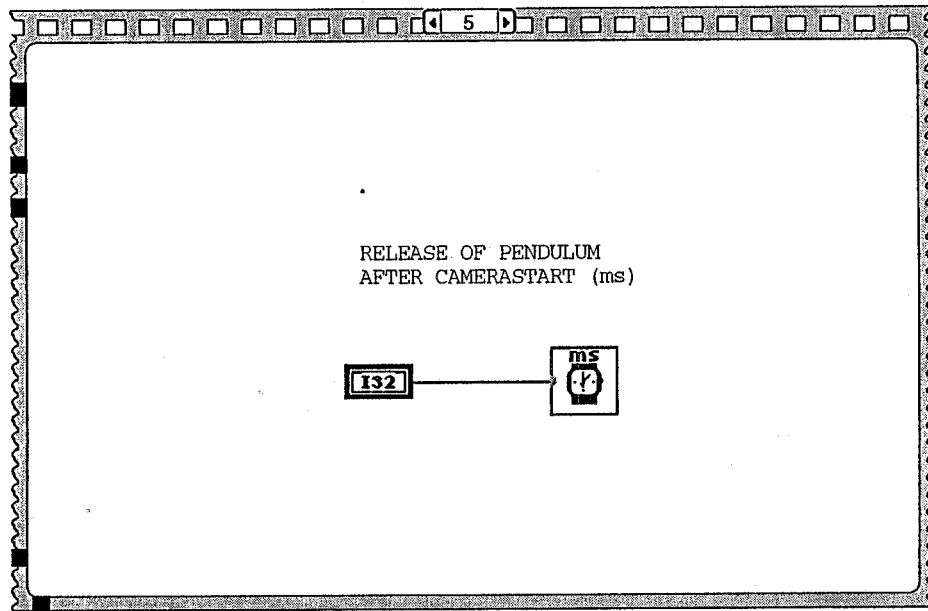
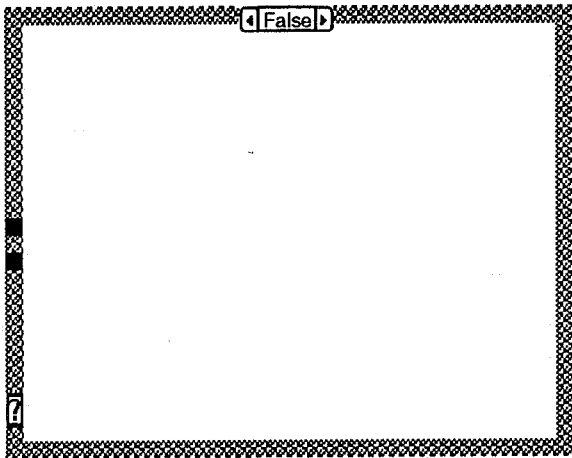


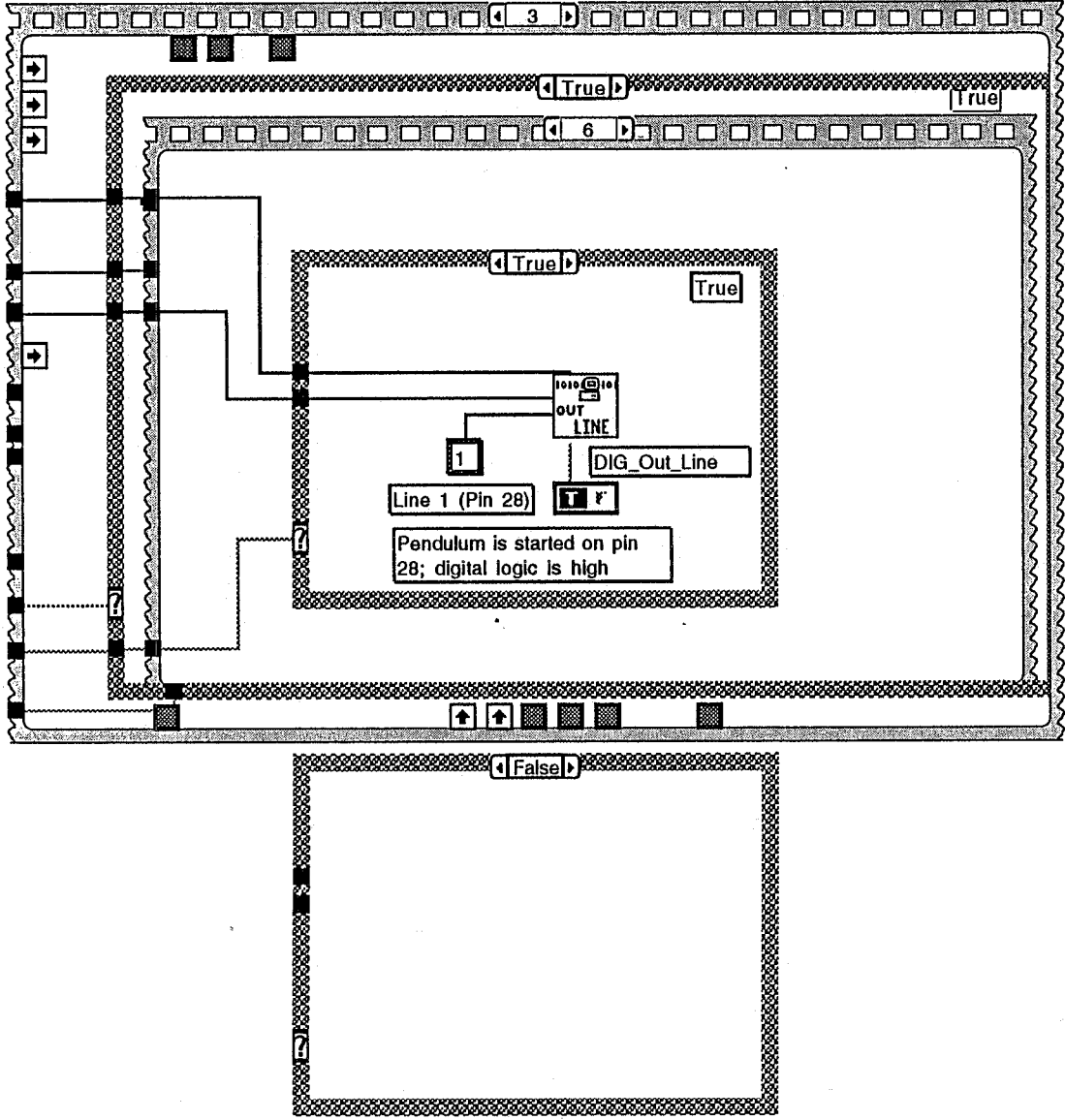












False

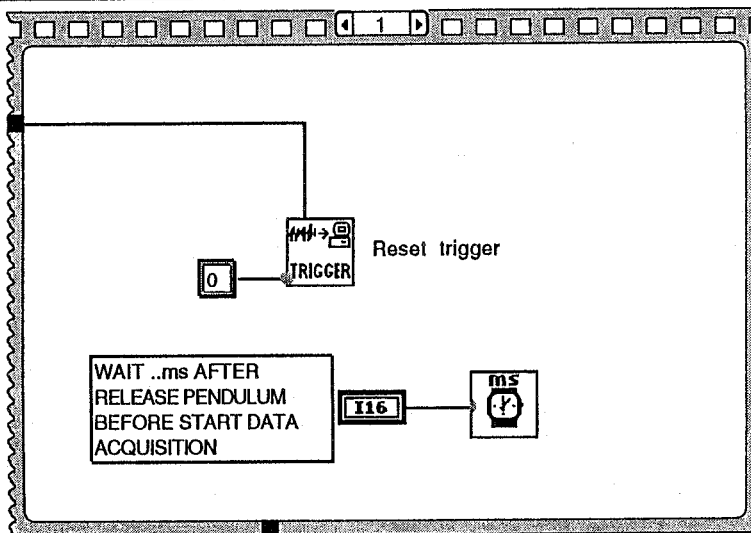
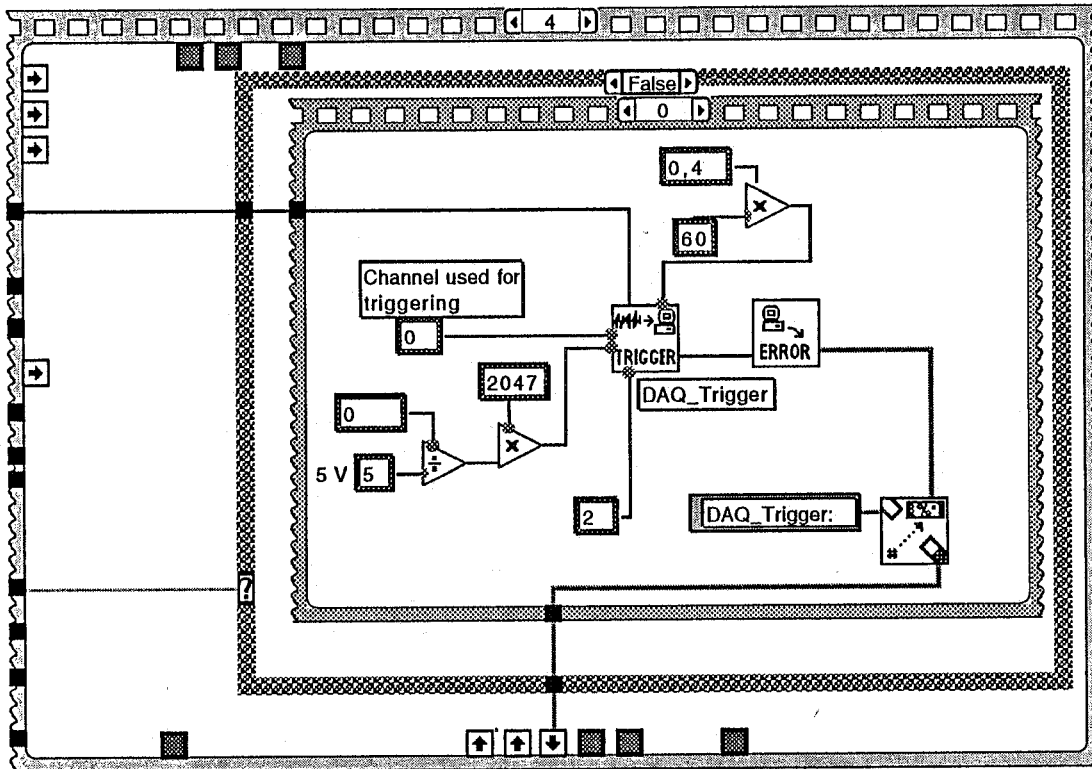
PORT A:

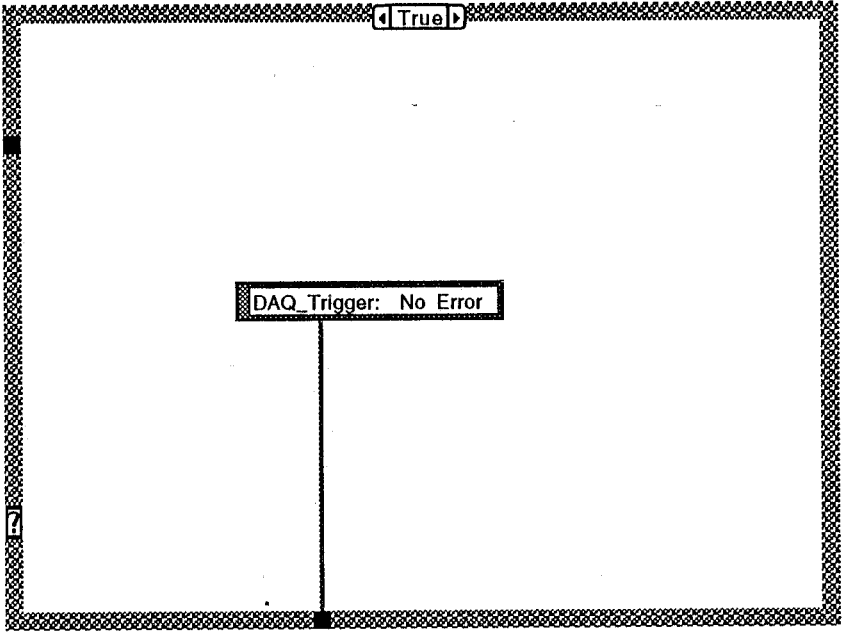
Line 0 (Pin 25): -
Line 1 (Pin 27): Camera on
Line 2 (Pin 29): Camera off
Line 3 (Pin 31): -

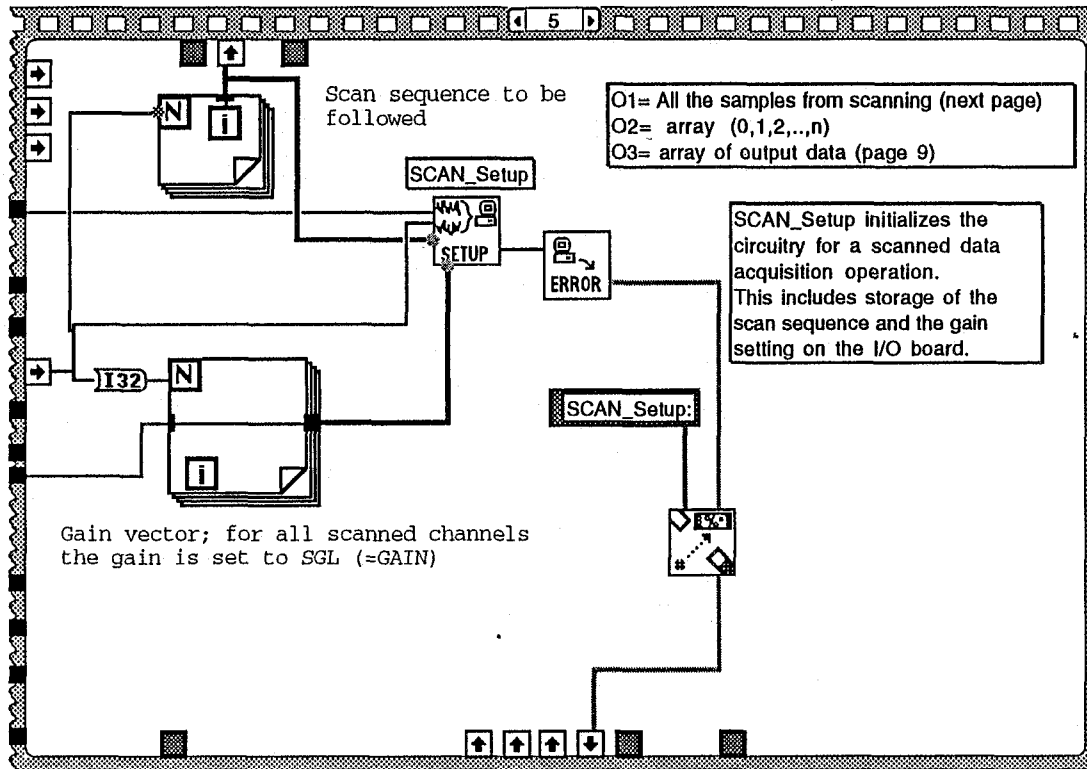
PORT B:

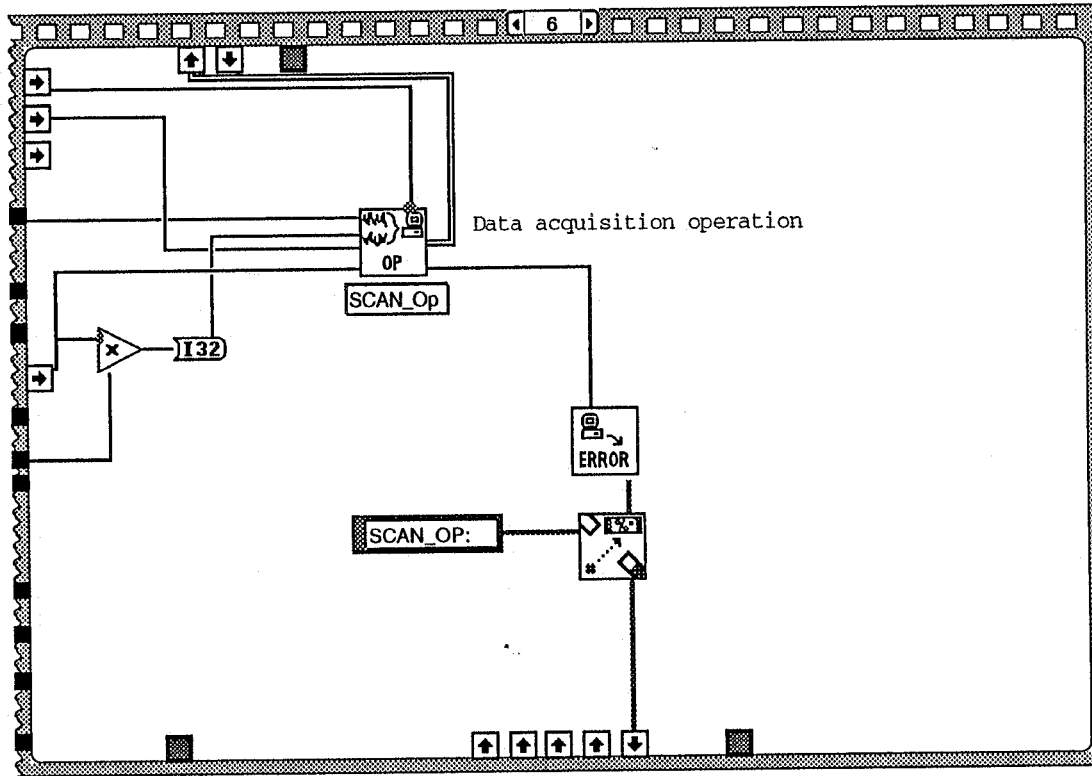
Line 0 (Pin 26): -
Line 1 (Pin 28): Release of pendulum
Line 2 (Pin 30): -
Line 3 (Pin 32): -

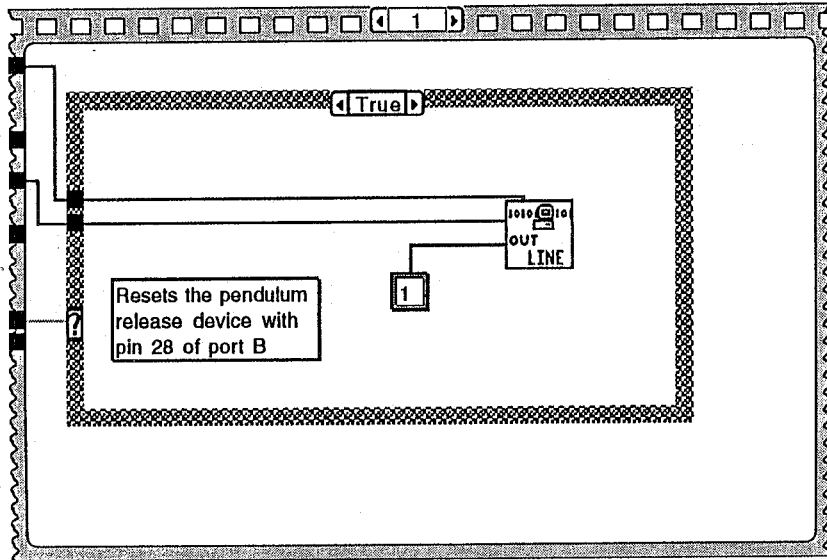
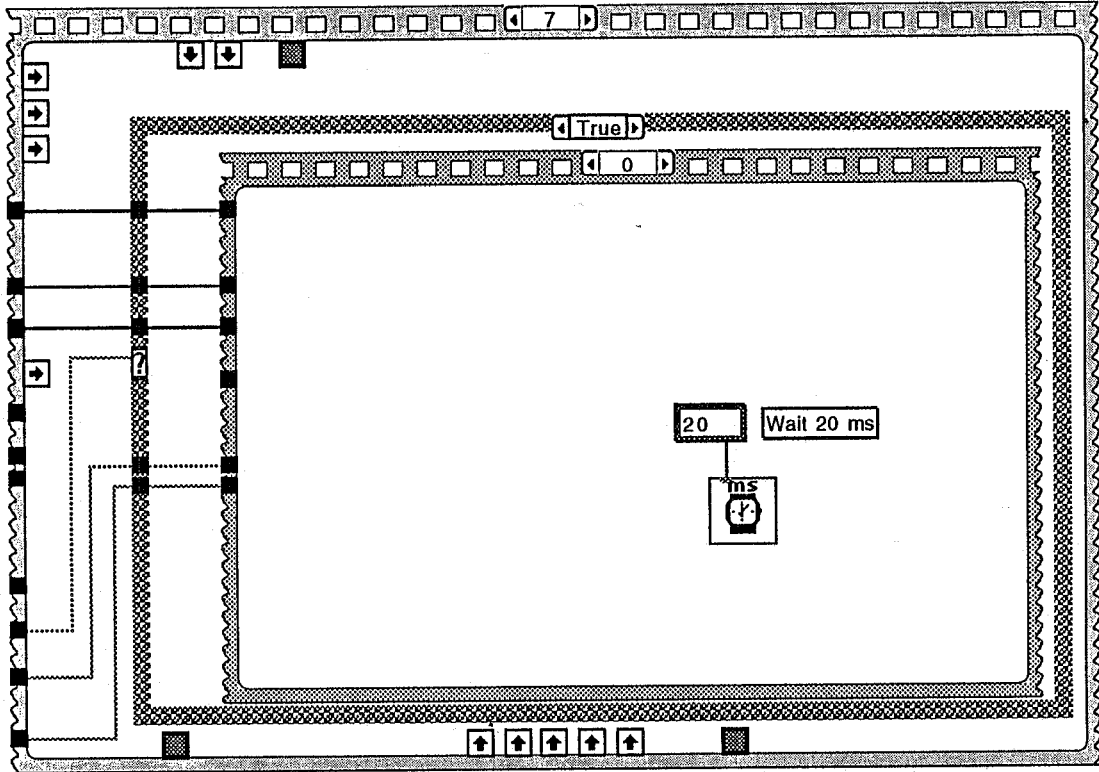
DIGGND: Pin 33

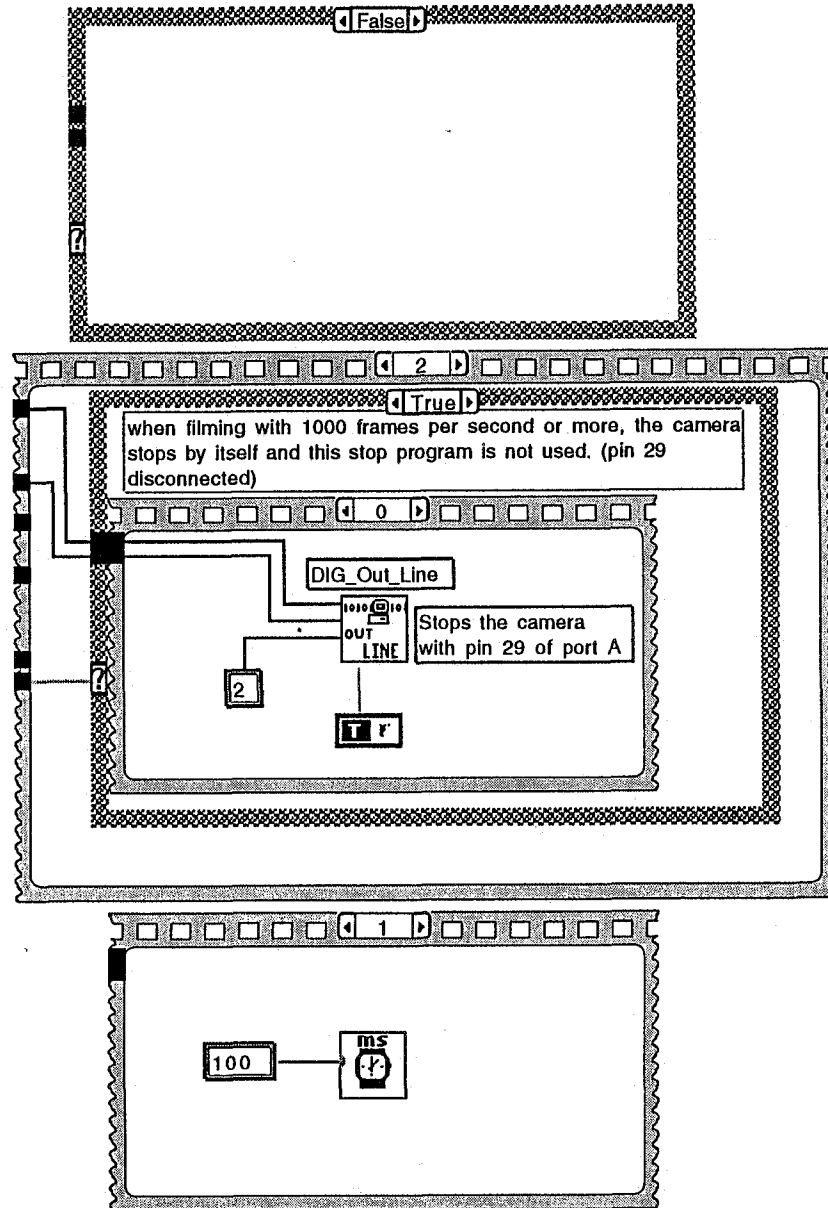


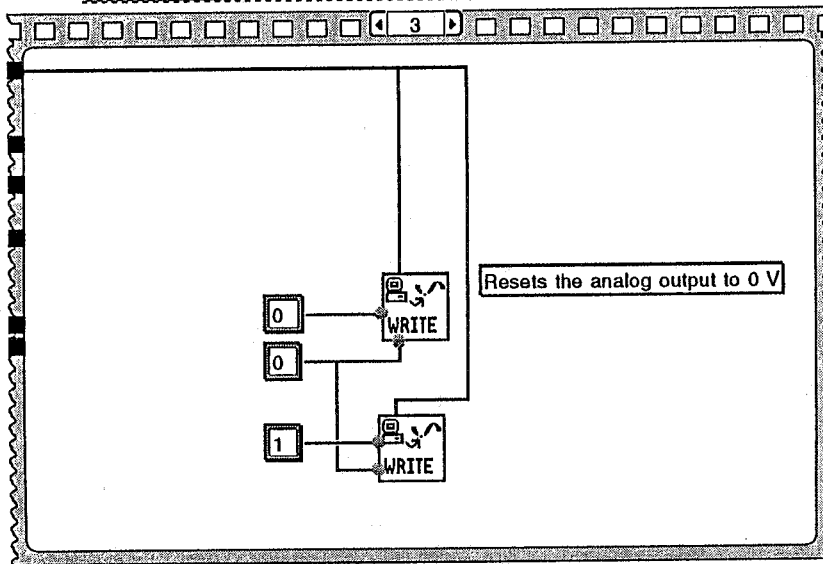
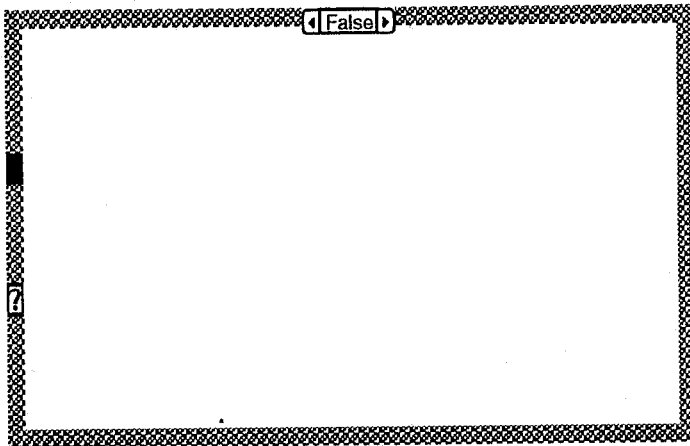
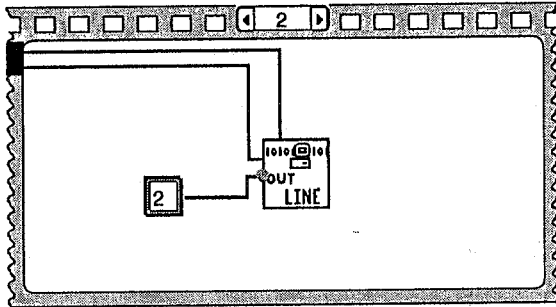


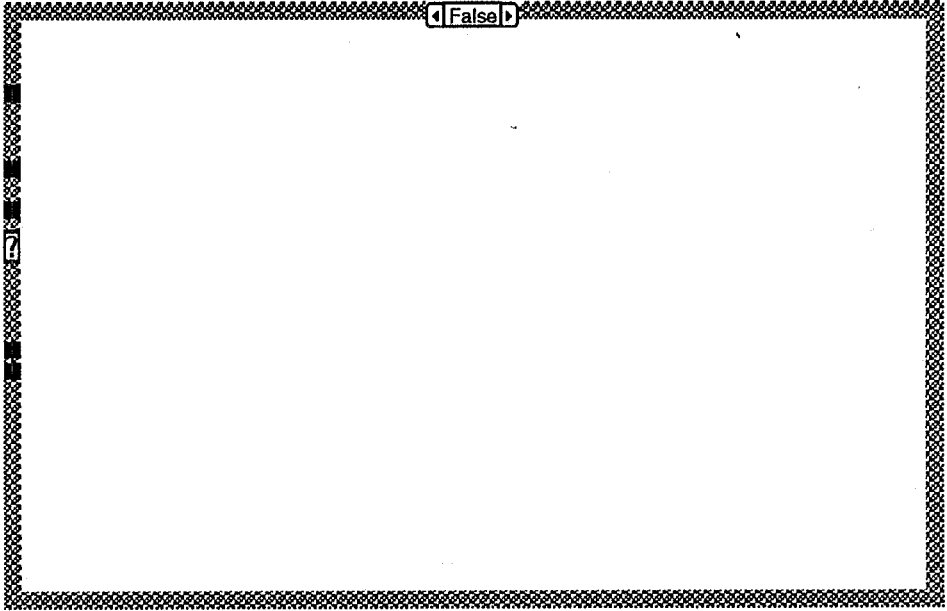


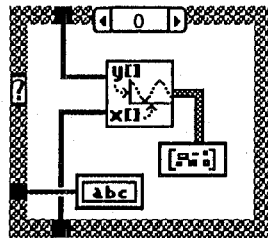
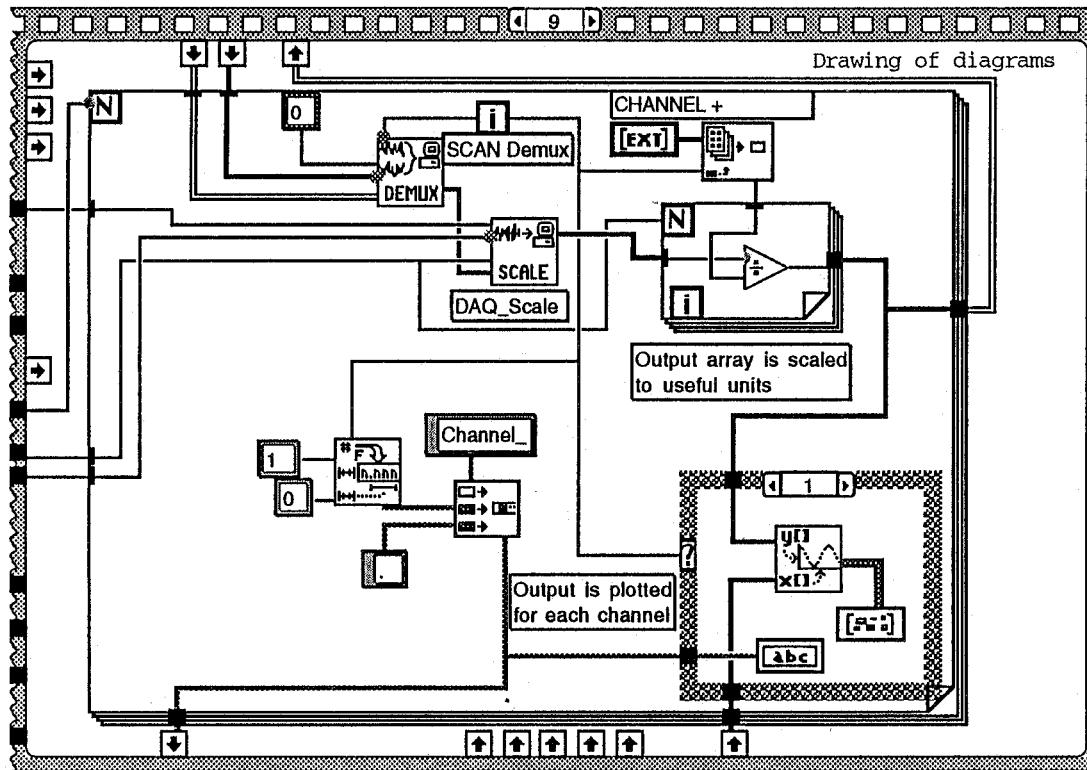


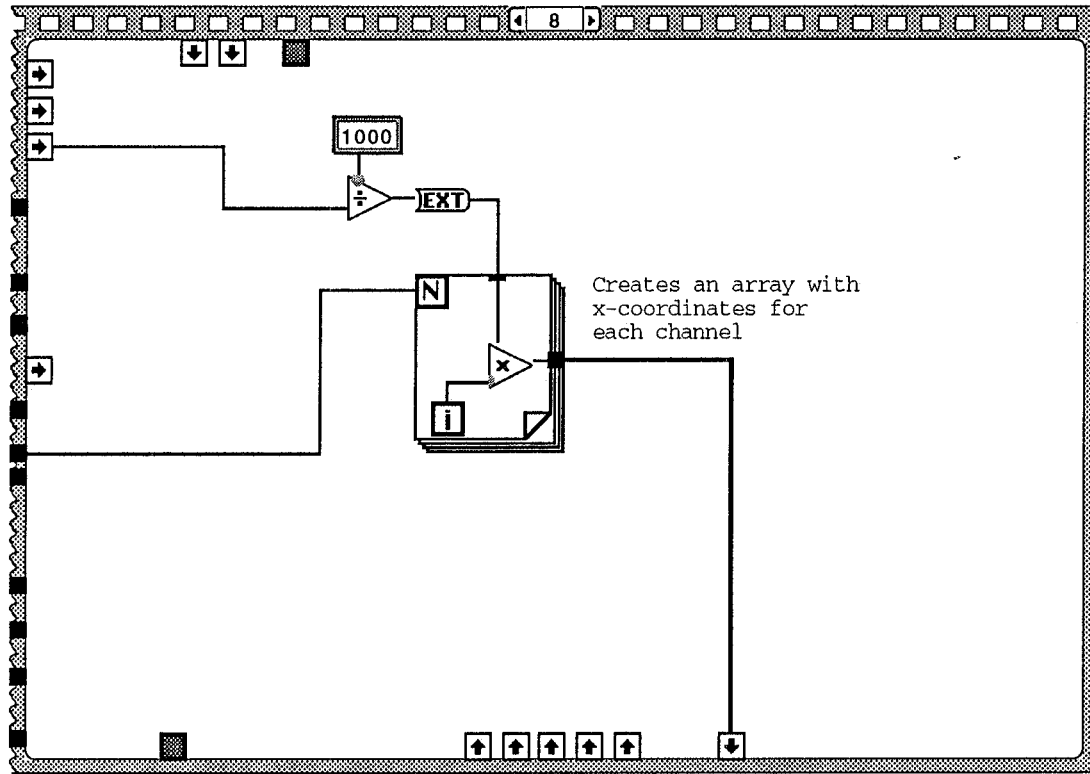


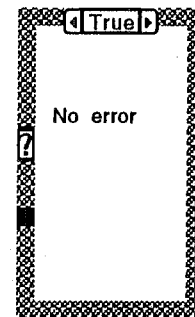
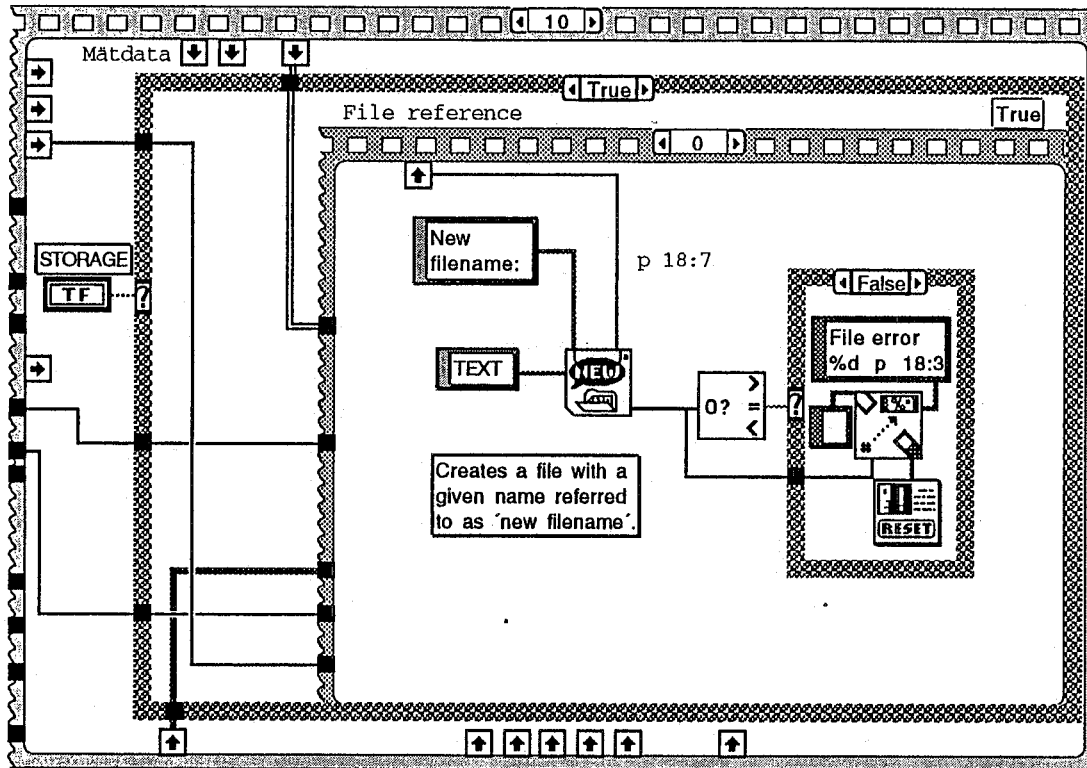


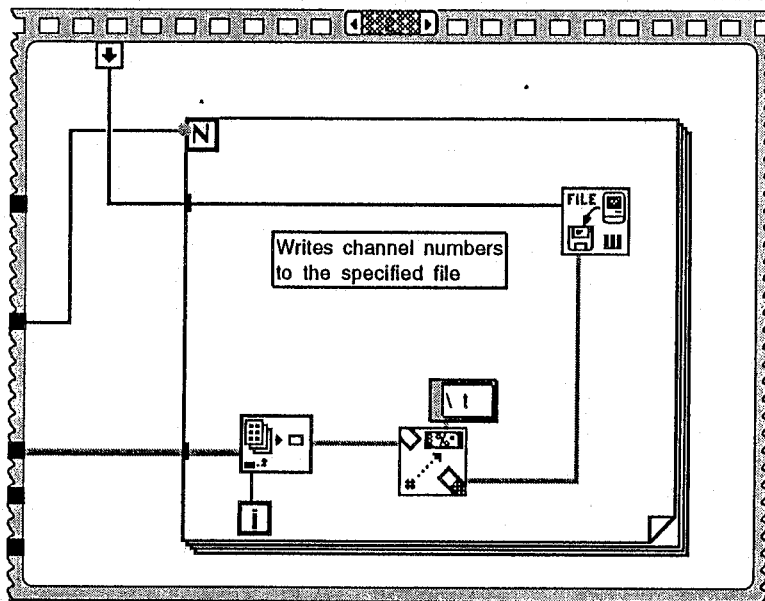
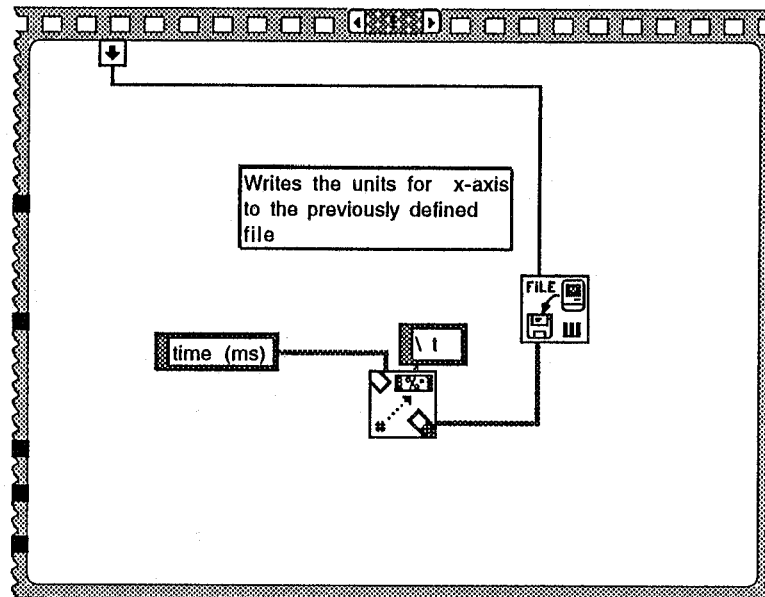


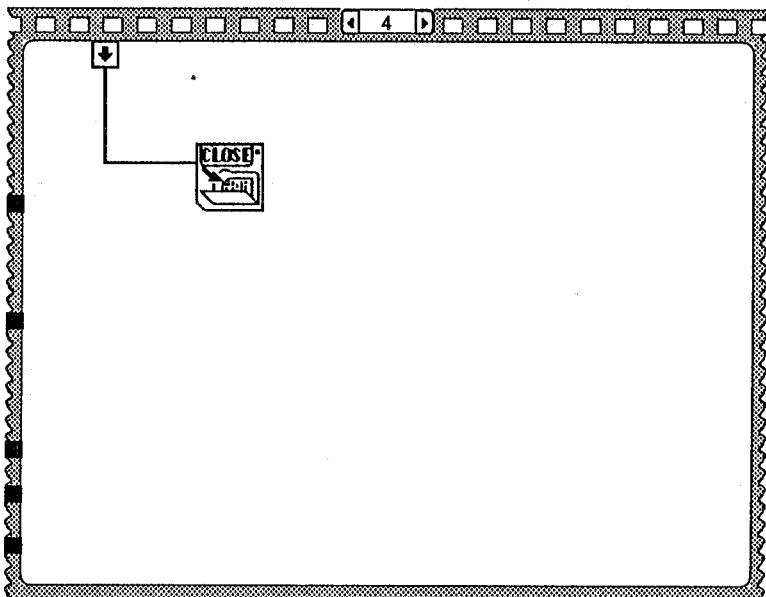
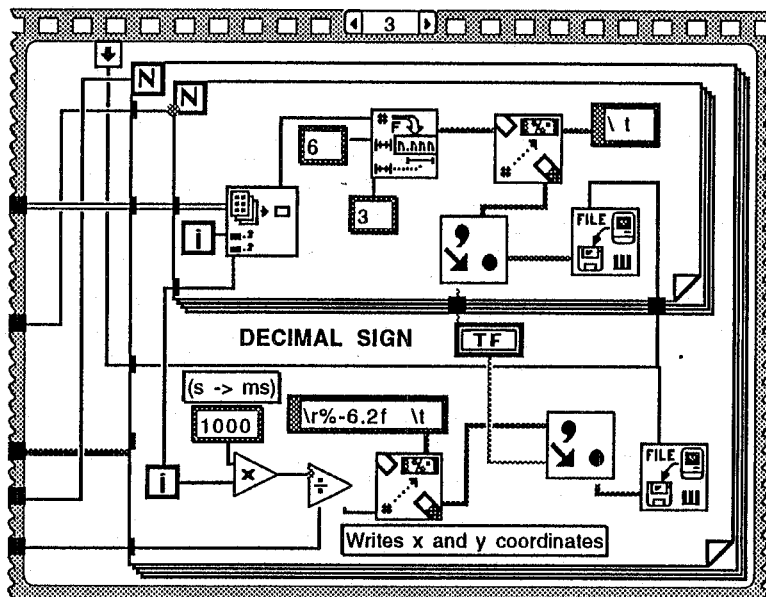


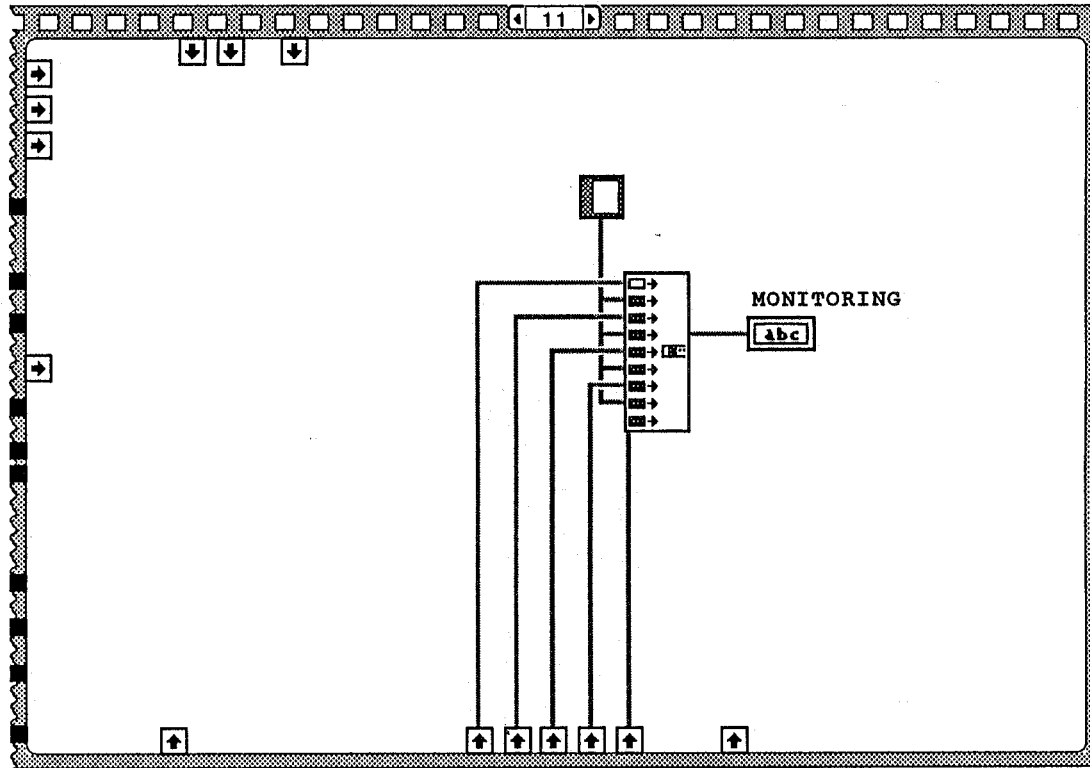












Appendix D: Laugh behind my back

Finally it might be a good idea to give an impression of all the things that might go wrong when setting up an experiment. It has caused a lot of disappointment, but these things happen and can not be avoided.

When the accelerometers were ordered we were promised that they would arrive within two weeks. A few days later the company called and said it would be 6 weeks, because the accelerometers were not in stock (as promised) and had to be manufactured. After two months other (better) accelerometers were sent, because the factory on the Virgin Islands, making the ordered version, had been struck by hurricane Luis.

The department of Injury Prevention had just moved. A lot of the equipment was still packed in boxes. Nobody knew where certain things could be found and half of the needed materials had to come from an old laboratory 200 m downhill. My physical condition has made considerable improvement due to the many walks there and back.

Just when the connections to the amplifiers were fixed, these same amplifiers were said to be taken to Stockholm for experiments there. For our set-up the connections had to be modified to fit into the computer, which also had the possibility to amplify. Of course some reprogramming had to be done also.

The first time markers were added to the silicone gel, air bubbles popped up in the gel and spoiled the entire visibility. The gel had to be thrown away. But this gel was really good! It was like one massive piece of rubber attached to the perspex. Nearly one hour work followed to get the gel out and clean the model. Does anyone know a good solvent for silicone gel?

The whole set-up was very well functioning, until the crucial moment. As soon as the high speed camera started running, one wire of an accelerometer broke down and gone was the validity of this experiment and most of the self confidence which was left after 2 months.

For the second film there was not enough light. The available lightmeter was not able to give a aperture value for a shutter time of 1/5000 seconds. So the aperture setting was a (wrong) guess. No confidence left at all.