Manual for the 1C1M set-up

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Traineeship report

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Contents

Chapter 1

Introduction

This manual is written for use of the maglev test rig. The set-up was build to do research for the maglev track project. With this set-up the interaction between the permanent magnets in the sled and the levitation coils of the track can be investigated.

The manual contains a step-by-step plan how to build the set-up, how to connect all the sensors, what to watch out for while using the set-up and the best strategy for conducting experiments with this set-up.

The angle of attack in the former set-up, caused by using a rotary set-up, is to big to do meaningful measurements. The old set-up also restricted the minimal gap between the coil and the permanent magnet to almost $10[mm]$. In the new set-up this is reduced to $1[mm]$.

Furthermore the read-out of the current sensor had to be transmitted wireless, which caused extra noise. The arm on which the coil was mounted wobbled a little bit, this caused the deflection to the null-flux axes hard to determine.

As a last remark, all the referenced files are bundled with this manual in a zip package.

Chapter 2

Building the set-up

2.1 Parts

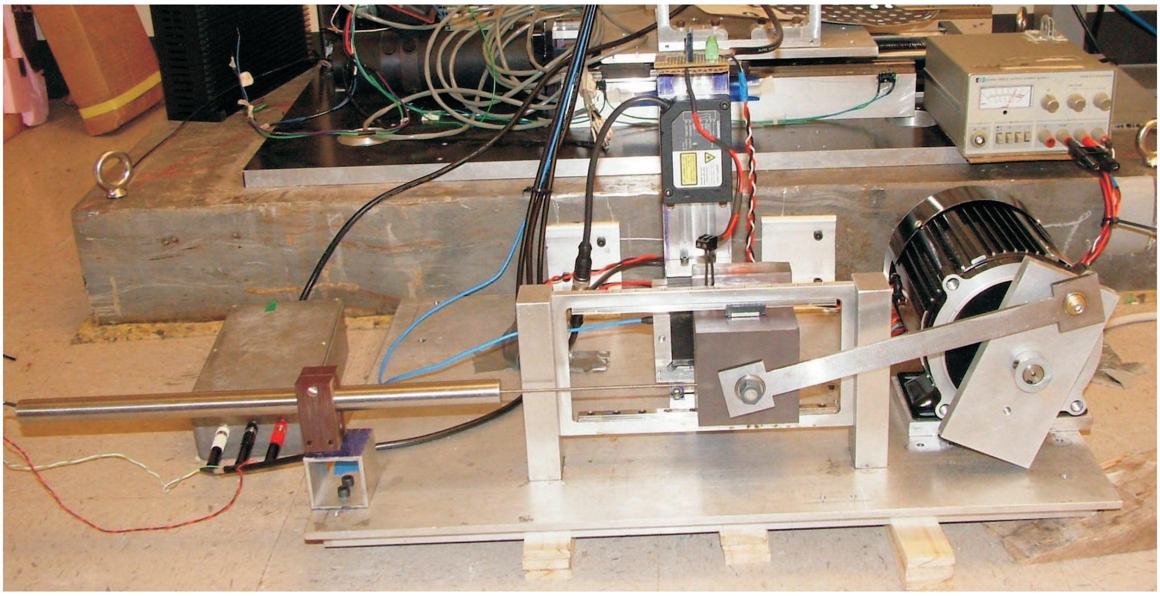

Figure 2.1: General overview of the set-up.

Labview equipment There is a tool in Labview, called Measurement & Automation, with which you can check if the card is installed correctly. When Labview is working properly use the standard data acquiring *.vi. Set all the preferences, e.g. sample time $1[s]$, number of samples $1000[-]$. Acquire all seven channels, i.e. X, Y and Z-force[1], X-displacement, Y and Z-laser and current. Remember that all the m-files for data processing are written in this sequence, so it's easiest to maintain this!!

electronic scope The scope is used to monitor a few variables during the experiment. You need all four inputs of the scope for the Y/Z lasers, X-displacement and current sensor. Get the signals by connecting them to the Labview board by means of a T-piece. Let the scope calculate the average of the Y/Z lasers. Use this to position the magnet with respect to the coil. Also calculated the period of

[1]This is viewed from the force sensor. Thuis makes X = lift, Y = drag and Z = guidance

the X-displacement sensor, this will give the speed of the experiment in Hz. Use the current sensor signal to verify if the experiment is running smoothly. When this signal is breaking down, either the sensor cable is about to snap or the set-up is breaking down.

Electro motor The electro motor which is used, is far from ideal, but fulfilled it's purpose. It's a big asynchronous electro motor. You can control the speed (open loop), by turning a knob. When switching the motor on, you have to kick start it. Take this literally, just push the rotary disk, to give the motor some initial speed. Because the motor is very bulky, it produces strong vibrations. The way it is bolted down, see figure 2.1, on the baseplate makes matters worse. This needs to be improved, because it's also very hard to get the motor in place.

constructional parts There is a part list in appendix A which enumerates all the parts. The CAD drawings are named according to the part number. Some of the parts were borrowed from other set-ups, reclaim or remake those parts. Use figure 2.1 as an overview and the other more detailed figures to put sub-assemblies together. There are also original CAD drawings or pictures available.

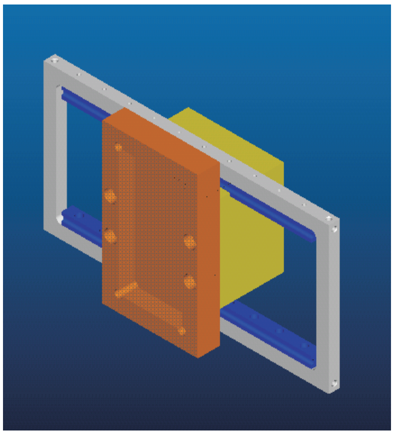

Figure 2.2: Sliding mechanism, mounting of the coil.

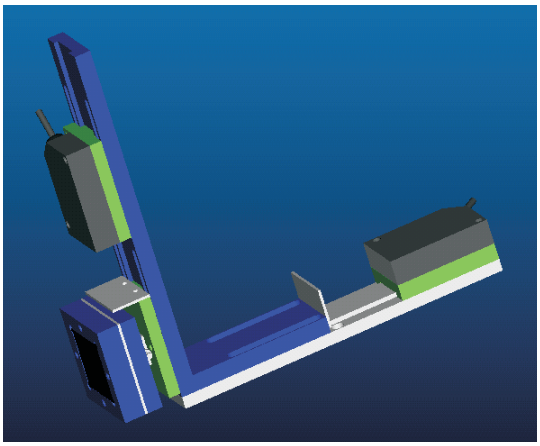

Figure 2.3: Force measurement, mounting of the magnet.

2.1.1 Sensors

Force sensor Use figure 2.3 to put together the magnet holder and force sensor. Don't put the magnet in place before preloading the force sensor. Keep in mind that the force sensor is very easily damaged. When all the pieces are together, let the magnet slide into it's holder. Be very gentle, since the magnet is brittle and is eager to slide into it's holder, due to magnetic forces.

Current sensor When the current sensor is still intact it's very easy to implement. Otherwise use the file Current_sensor(NT-datasheet).pdf to rebuild it[2]. Rebuild or still intact, just tape the PCB to the top of the set-up, see figure 2.4 for details. Connect the cable to the coil, note that the wires can be a little bit eroded. Check this, because a bad contact will ruin your experiment.

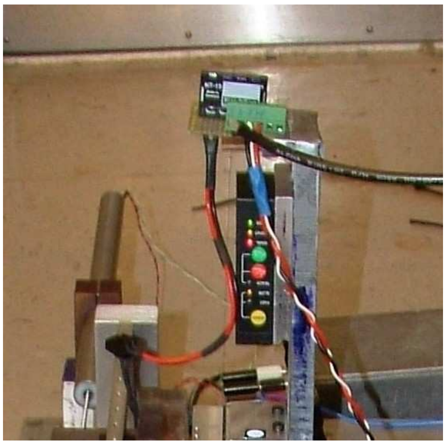

Figure 2.4: Current sensor mounting.

X**-displacement sensor** This sensor was borrowed from professor ?? [3]. The X-displacement sensor makes use of a Linear Variable Differential Transformer, hence the name LVDT [4]. The location of the sensor in the set-up is depicted in figure 2.1. You can find the (original) calibration information in appendix B.

Y **and** Z **displacement sensor** The lasers are fastened down with two screws on there mounting blocks, as can be seen in figure 2.1. The Y-laser is fixed, but the Z-laser can be moved freely. This is needed to extend the range of the Z-laser, for more details see section 3.4.

[2]Use a small piece of PCB and try to reconstruct it from pictures.

[3]Ask Prof. Hector Guiterrez for the correct name

[4]For more information see `http://www.macrosensors.com/ms-lvdts_prod-dc750.html` or `http://www.macrosensors.com/ms-lvdts_faq-tutorial.html`.

2.2 Installation

For a description how the set-up should look like see the *.jpg pictures or see the CAD drawings in the previous section. Rebuild it accordingly. Be aware of any vibration sources, these will become very distinct at high speeds. Below is a checklist of what to build first.

- Take the baseplate [5] as starting point (really nothing attached to it).
- First put the motor in position, do not bolt it down yet.
- Mount the sliding mechanism, without the coil(mount). Try to mount the motor aligned with the sliding mechanism, by means of the slider block.
- From the force assembly, take the force support and fasten it to the baseplate.
- Take the rest of the force assembly, except for the lasers, and put it in place.
- Now attach the rotary disk to the electro motor. Use two shaft collars to fasten it. Then attach the piston-rod assembly in either 3 or $5[Inch]$ mode.
- Put the magnet assembly in position and the coil mount in either 3 or $5[Inch]$ mode[6].
- Bolt down the X-displacement assembly.
- Put the lasers and current sensor in place.
- Finally attach the baseplate to a fixed structure. Previously the aluminum of the earthquake set-up was used.

[5] The baseplate is scrap material and has many unused/old holes. Therefor it may be hard to figure out which holes to use. So first put everything in place without bolting anything down.

[6] This determines whether the coil has to be placed in Z or X mode respectively.

Chapter 3

Implementing the sensors

In general when implementing the sensors, make sure that you don't create groundloops. These loops will create all kinds of unwanted electrical noise. You should also secure all (sensor) cables, e.g. with tie rips, especially the cable of the force sensor.

3.1 Force sensor

If this is your first time, just run through the procedure once, especially the paragraph about preloading the sensor. Just perform each of the steps, only to get familiar with preloading the sensor. In the second try, you should shoot for accuracy, keep in mind that this procedure is hard and will usually require more tries.

Mounting the sensor How to mount the sensor is already discussed in section 2.1.1. Use the copper stud, because this was used during factory calibration, and bolt the parts together. These are magnet holder, copper stud, force sensor and sliding pad. For use of the washer the following should be remarked. The washer is not necessary for holding the sensor in place [1]. However in the design it was mistakenly taken into account, therefor it should be used

Connecting the Signal Conditioner (484B Series) There are two Signal condition boxes, one for preloading and one for normal operations. Take the 484B series and run trough the following steps. Check the manuals for information why to do this.

- Turn the 484B Series on without anything connected.
- Check if the scale is in yellow (open circuit).
- Turn the 484B Series **off** and connect the output to a scope.
- Now connect the sensor to the input.
- Refer to the calibration certificate (Z-direction) for the sensor and set the bias switch accordingly [2].
- For calibration purposes, the AC/DC switch at the back should be in DC mode. AC mode is for normal data acquisition. This option is not used since three axes need to be acquired instead of only one. To acquire the three axes, use the 482 Series signal conditioner.

[1] This was concluded after consulting the manufacturer

[2] If the sensor bias is from $9.5 - 13[V]$ (normal) use the $11[V]$ position.

- Turn the 484B Series **on** and check that the scale is green, which means normal operation. Yellow means open-circuit, a loose connection. Red means short-circuit, so you should switch everything of immediately.
- Wait for a few minutes until the system warms up and then tweak the knob at the front until the output signal is zero.

Preloading the sensor This is the part where you want a friend to help you since this is almost impossible to do on your own. The idea is to preload the sensor to $1000[lbs]$, because the same preloading was used with calibration. To do so, we need to apply force to the sensor up to when the output reaches $25[V]$.

However, there are two problems with this. Firstly, the steps cannot exceed 10V as the sensor output will become non-linear and when reading it, it will either give a bad value or just clip the signal. Secondly, the application of the force (in each step) should be continuous and relatively fast without overshooting it. The idea here, is that once we load the sensor, the output will start decreasing rapidly up until it goes back to zero.

Another problem is that you need to keep the axes perpendicular for a correct read-out in your experiment. Use a square to arrange the axes accurately and keep them secure while preloading with that square. This is when your friend comes handy, to either preload or hold the axes perpendicular.

Also the bolts may slip during preloading this results in a very unpredictable resistance. Sometimes you have to turn the wrench all the way and sometimes you only need a small stroke

- Set the scope in a appropriate range, so you can see at least a $10[V]$ amplitude.
- Use a function in the scope, which holds the peak value.
- Apply force up until the output is less than or nearly equal to $10[V]$ in a single continuous step [3].
- Write down the maximum voltage reached in that step.
- Wait until the output signal, which is decreasing, reaches zero volts [4].
- Repeat this procedure up until the sum of the maximum voltages reaches $25[V]$.
- The last of the steps should be the most important and difficult as one needs to reach $25[V]$ as accurate as possible, but once this is done the sensor is ready for use.

Now disconnect everything and place the sensor in the set-up. Be careful how to guide the sensor cable since any strain in the cable is a preload on the sensor. Switch the 482 Series, without anything connected, and check if every channel is in yellow. Now connect the three sensor outputs to the 482 Series inputs. And then connect the outputs of the 482 Series to the Labview board.

3.2 Current sensor

Information about this sensor can be found in Current_sensor(NT-datasheet).pdf. The sensor is stressed mechanically and there were some doubts about the linearity in the lower regions of the range. Therefor some measurements were conducted, the results are presented in NT15_calibration.m. Both before as well as after the experiments the sensor was found to be fine.

Power is supplied to the sensor by the grey power supply, the sensor draws + and - $15[V]$ and needs a ground connection too. It shares this power supply with the two lasers who require + $15[V]$ and ground. When you switch on the supply make sure it indicates $15[V]$ and that the amperages is according to the laser and current sensor specifications. Finally connect the signal cable to both the Labview board and the scope.

[3] Note that during the first stroke, the voltage response is lower than during consecutive ones.

[4] This is really slow, so you might be interested in stopping the wait when it reaches around $100[mV]$ and account for this in you next reading.

3.3 X-displacement sensor

This sensor is one of the easiest in handling. In figure 3.1 the connection scheme is shown. Connect it accordingly and use the coax cable for the Labview board.

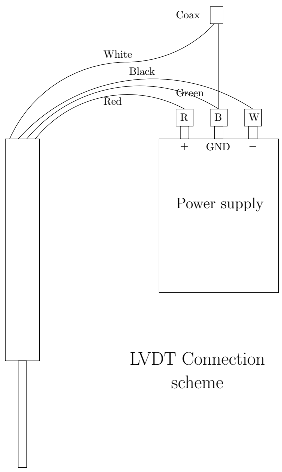

Figure 3.1: Connection scheme of the LVDT

Since the displacement sensor is based on magnet principles, you should watch out for the interference caused by the permanent magnet in the set-up. This has an effect on both linearity and a zero shift. When the magnet is nearby the output range from $\pm 10[V]$ shrinks a little. The range also shifts a little, so e.g. $0.00[V] \Longrightarrow 0.10[V]$. You shouldn't worry to much about the linearity issue, since we are only interested in the frequency of the sine wave. The amplitude can be measured in the set-up and therefor is already know. Still it is wise to keep it in the back of your head. The zero shift is a bigger problem[5]. You should re-adjust this back to zero every time you start an experiment.

3.4 Y and Z displacement sensor

Connecting the power supply and signal cables of the lasers is the same as for the current sensor. On the lasers there is a teach mode, which recalibrates the measuring range. In the past this has been done a couple of times. It is advised to recheck this.

Further the experiments require a large range in the Z-direction. This range is larger than the Z-laser can supply. Therefor the laser is mounted on a sliding mechanism. The procedure, e.g. moving upward, is as follows.

- Find the Nullflux axis.
- Push the laser in upward direction until it goes out of range. Read out the scope and fasten the slider when there is a mean of e.g. $9.98[V]$. Be careful not to stop at $10.0[V]$, since you loose a digit in that way. Write this down.
- Now push the magnet upward until the sensor goed out of range again in a same way as the previous step. Again write the voltage down.
- When you subtract the previous steps and use the scaling factor of the laser you can calculate the deflection δ from the Nullflux axis.
- Repeat the steps until you reach the desired deflection.

[5]While analyzing the data, the X-position measurement determines the analytical and algebraic model in time. An incorrect zero point mis-aligns the data with these models.

Chapter 4

Initialization and operation

4.1 Check list for initialization

In the previous chapter building the set-up and implementing the sensors were treated. It is assumed that everything is in place and you can begin your first experiment. Below is a list which you should follow step-by-step every time you start up an experiment. Sometimes you may want to refer to the previous chapters.

- Check if all power is on.
  - Labview (board, computer)
  - Electro motor
  - Combined sensor supply (correct voltage, amperage)
  - X-displacement sensor supply
  - Force-sensor supply (482 Series)
  - Scope
- Let the sensors warm up (especially the lasers, up to 15 min.).
- Open the correct *.vi in Labview, make sure all the settings are correct.
- Check if all the sensors are connected correctly to the Labview board.
- Check the channels and calculations of the scope.
- Find the Null flux axis to determine the Z-reference.
- Find the minimal Y_{gap} for Y-reference minus know material in between magnet and coil
- Find initial force and current measurements and check for noise levels. To do this, acquire one shot in Labview without anything moving.
- Put magnet in desired position.
- Position X-measurement to zero.
- Start experiment (you have to swing-start the motor)
- Capture single shots for different speeds[1] (check the scope if the speed is constant)

[1] In the previous experiments speeds of $3, 5$ and $7[Hz]$ were used

4.2 Operating the set-up

While operating there is a lot going on which requires your attention. First of all don't drive the motor with large speeds, since this causes vibrations which may damage parts of the set-up. Keep checking the scope if the desired speed is reached. You will experience that this is quite hard, especially when you want to maintain a constant speed[2]. Of course you should also try to determine if the sine wave, generated by the X-displacement sensor, is smooth.

Secondly check the current read-out on the scope. When the signal is breaking down this may imply that the cables on the sensor are either badly connected, or about to snap. This may happen because the cables are subject to a lot of strain, still they should hold for about 150-300 measurements.

Further when the Y_{gap} is very small check that the coil isn't hitting the magnet. Also check for other irregularities due to vibrations, e.g. the force-sensor cables become strained.

When everything seems to be running smoothly, and the motor is running on the correct speed, capture one shot of data. Do a fast-check on the data in Labview. Determine if all the sensors have a decent read-out[3], check if read outs of the Y/Z lasers remained constant.

When successfully captured some data collect all important read-outs, e.g. in an excel sheet. Write down the motor speed according to the scope, the Y- and Z-positions of the magnet and anything to remark. Save the data with logically numbered files, e.g. `*-1.txt`.

[2] Since there is no (feedback) control.

[3] The Force-sensor has a very poor read-out, so don't pay to much attention to this. Also see chapter 6 for this.

Chapter 5

Data processing

After running a sequence of experiments, processing the data is almost completely automated. To keep this well-organized some preparations have to be taken. When these steps are properly followed, all the data can be analyzed quickly and with almost no effort.

First all the data text files have to be given a header. The header contains all relevant information about the experiment. The numbers below the column names (Date, Time, etc.) are conversion factors for that column. For example:

```
X direction experiment, number 1
X0 offset =  [m] (range should be +-V)
Speed = [Hz], y-pos = [m], delta = [m]

Date  Time   ForceX[N]  ForceY[N]  ForceZ[N]  Xpos[m]    Ypos[V]  DELTApos[V]  Current[I]
1     1E-3   93.9850    93.4579    178.126    7.4706E-3  1        1            6
```

In matlab save a variable containing [Number δ-pos Y_{gap} Hz] to a matlab workspace, e.g. `*Ini.mat`. Then run `Labview_conversions.m` in the same directory as the measurement data and `sinefit.m`. This calculates a fit in a least squares sense of the X-position measurement and returns the correct speed in $[Hz]$. And it will automatically save all the relevant data in a structure per experiment and saves all these structures to one workspace file.

Then use the same `*Ini.mat` file in the mathematica file `AnalyticalSimulation.nb`. You need to do some adjustments to this file dependent of a X or Z type experiment. After calculation (these can take up to some days!) export and save the data in `*Sim.mat`.

Now use both the data and simulation matlab workspace file in `DataSimulationCompare.m`. This file automatically updates the data workspace file with the simulation values, the algebraic values calculated in `DataSimulationCompare.m` and other relevant values. While this file is running, check if all the plots are correct. When the X-position is not fitted correctly use `Labview_conversions.m` to straighten this out. Furthermore use the filter options to get better force data.

As a last remark the file gives a better fine tuning for the algebraic model to the analytical model over the range of the experiment. This can also be implemented for the (filtered) data.

Chapter 6

Recommendations

Although the set-up was build out of scrap and borrowed material, the experiments were useful. Still there is a lot to improve. If the experiment will be executed again, one has to try to shoot for higher speeds. When doing this the set-up should be improved. Improvements can be made in almost every part of the set-up and are listed below.

First of all, already at low speeds there is a vibration problem. This can be solved by either fixing the baseplate to a better base block, or using a new and more rigid baseplate. Further replacing the motor or remounting the motor should be considered. The motor is very bulky and is fixed right to the baseplate, this is the main source of the vibration problems.

The experiment is done open-loop, this is far from desired. Implementing a controller on the the motor will give better experimental data and will reduce some hassle while conducting experiments. Nevertheless it will take some time to implement it.

The model will have to perform with high speeds. Because the stroke of the experiment is so small, high speeds will require at high rotation speeds. This will cause vibrations, and the motor has to be capable of producing the required rpm. Better is to enlarge the stroke of the set-up considerably and search for another sensor. This gives as extra benefit that the maximum acceleration is brought down.

When you are concerned about the maximum allowable G's, recall that everything has to be non-metallic around the coil, to avoid eddy currents and other disturbances. Therefor the plastic screw to mount the coil is the bottleneck. Breaking these screws during an experiment is shown in practice!

Another problem is the force sensor. For the purpose of this experiment it is over-dimensioned. Using an aggressive low-pass filter improves the data. Unfortunately not enough, therefor the experiments can only confirm the basic shape of the forces.

And finally when you have the chance to glue the coil in his holder again, turn the coil front to back. The connecting wires produces a non smooth surface at the moment. When turned front to back there will be a smooth surface and the minimal y-gap is decreased once again. Also you may want to find a solution to prevent the current sensor cables from breaking.

Appendix A

Part list

Name	Origin[1]	Borrowed[2]	Material	Part number
Baseplate	new	-	aluminum	01
Electro Motor	new	-	-	02
EM rotary disk	modified	-	aluminum	03
Piston-rod.asm				04
Bearing1	new	-	metal	04.01
Bearing2	new	-	metal	04.02
Rod	new	-	steel	04.03
EM attachment	new	-	steel	04.04
Coil attachment	new	-	plastic	04.05
Rail.asm				05
Rail studs	new	-	aluminum	05.01
Frame	new	Nullflux experiment	aluminum	05.02
Rail	new	Nullflux experiment	aluminum	05.03
Rail-slides	new	Nullflux experiment	aluminum	05.04
Slider block	new	-	plastic	05.05
Coil mount	new	-	plastic	05.06
Coil top	new	-	G4 plastic	05.07
Mount screw	new	-	plastic	05.08
X-displacement.asm				06
Sensor	new	prof??	-	06.01
Sensor-rod	new	prof??	steel	06.02
Sensor mount	new	prof??	plastic	06.03
Sensor elevation	new	-	aluminum	06.04
Force.asm				07
Force-support	new	-	aluminum	07.01
Force-Lprofile	new	-	aluminum	07.02
Y-laser mount	new	-	aluminum	07.03
Y-laser reflect	new	-	aluminum	07.04
Z-laser mount	new	-	aluminum	07.05
Z-laser reflect	new	-	aluminum	07.06
Y/Z laser	new	Maglev sled	-	07.07
Magnet.asm				08
Magnet-sled	new	-	aluminum	08.01
Washer	old	force sensor	-	08.02
Force sensor	old	force sensor	-	08.03
Force coupling	old	-	aluminum	08.04
Frame cover	old	-	plastic	08.05
Magnet frame	old	-	aluminum	08.06
Magnet	old	-	-	08.07
Preload stud	old	force sensor	copper	08.08

[1] New, old or modified part wrt the old set-up

[2] Gives the origin of the part, if applicable

Appendix B

LVDT

Macro Sensors
PENNSAUKEN, NEW JERSEY
DC-750-3000

Serial Number 19136
sensor output frequency response (-3dB) is $f_{sample} = 250[Hz]$

Independent linearity data for a least squares line, 12-01-2000

Measured $[Inch]$	Measured $[V]$	Calculated $[V]$	Deviation $[V]$
-3.0000	-10.20767	-10.18445	-0.02322
-2.4000	-8.14474	-8.14620	0.00146
-1.8000	-6.10024	-6.10795	0.00772
-1.2000	-4.05181	-4.06971	0.01790
-0.6000	-2.02349	-2.03146	0.00797
0.0000	0.00151	0.00679	-0.00527
0.6000	2.04938	2.04504	0.00435
1.2000	4.08413	4.08328	0.00085
1.8000	6.11998	6.12153	-0.00155
2.4000	8.15353	8.15978	-0.00625
3.0000	10.19409	10.19803	-0.00394

Scale Factor = 3.400 [V/Inch]
Calculated Null = 0.00679 [V]
Linearity = -0.114%

Wiring Code
Red = +15 [Vdc]
Black = -15 [Vdc]
Green = Ground
White = Signal