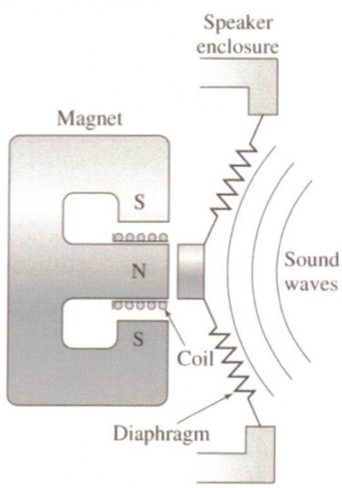
MAE 3724 Systems Analysis
Fall 2019

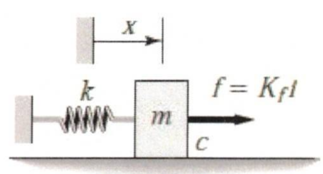
Laboratory Experiment 6
Step Response of an Electroacoustical System

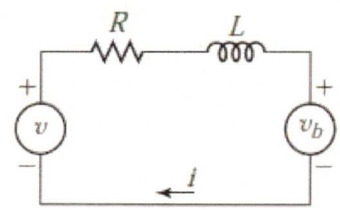
Background for Laboratory Experiment 6

The purpose of this experiment is to give you hands-on experience with an actual system of the type you have studied and modeled analytically, and a technique for measuring small displacements.

You will measure the step response of an electroacoustical system. The physical model is shown below.



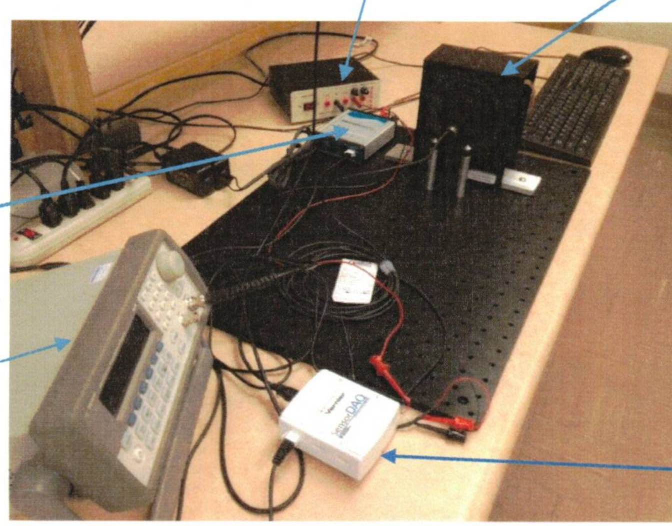




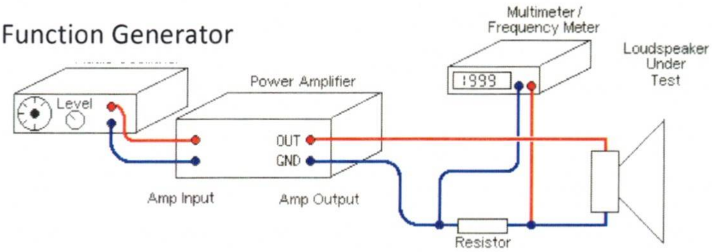
The motion of the center of the speaker cone is x. The motion is referenced to an equilibrium position.

The coil is connected to the center of the speaker cone so that it moves a distance x when the center of the cone moves a distance x.

Setup – Photo



Setup – Schematic for Measuring the Impedance of the Speaker



A DCDT (not shown in the schematic circuit) is used to measure the displacement of the center of the speaker diaphragm and attached coil. The output voltage reading of the DCDT varies based on the displacement of the moving core inside the fixed DCDT housing (see page 7) and the voltage being supplied to the DCDT. The input of the DCDT is connected to the Main Power Supply while the output is connected to a SensorDAQ. The SensorDAQ is connected to the computer. **Using the multimeter provided, measure the voltage being supplied to the DCDT (~10 V_{DC}) so that you can determine the effective sensitivity of the DCDT in mv/mm.** (You will need to do this in Part d) of the lab report). 56 $\frac{mV}{mm}$

Procedure for Determining the Impedance of the Speaker

Your Lab Teaching Assistant has already set up the circuit above so that you can first determine the impedance of the speaker. Using the impedance, you can determine the approximate value of the speaker inductance L and whether the assumption that $L = 0$ is a good assumption for the model. The resistor R_1 in the circuit above will be used only when measuring the impedance of the speaker electrical circuit.

Use the Multimeter to measure the value of the resistor R_1 and the resistance across the speaker R, and record them below; you will need this information for your Final Report.

$R_1 =$ 452Ω

$R =$ 6Ω

Use the Function Generator to apply a sinusoidal input to the speaker/resistor circuit (shown above) of frequency 1 kHz and voltage of 1 V_{RMS}, and an offset of $0\ V$. ($V_{RMS} \equiv$ root mean square magnitude) **NOTE:** The Power Amplifier has a gain of 2, so that its output voltage is two times the output voltage of the Function Generator.

Use the multimeter to measure the alternating voltage V_1 (RMS) across the resistor R_1. Record this value below; you will need this value for your Final Report.

$V_1 =$ 689 mV

Procedure for Determining the Step Response of the Speaker

Change the circuit so that the Power Amplifier is connected directly to the speaker (i.e., Remove resistor R_1).

You will measure the step response of the speaker using the Function Generator to supply an electrical input to the Power Supply for the Speaker, and a DCDT (see page 5) to measure the output displacement of the speaker diaphragm and attached coil.

Set the Function Generator to supply the circuit with a square wave of frequency 100 mHz, amplitude 1 V_{pp} ($V_{pp} \equiv$ peak to peak magnitude) and a DC offset of 0.5 VDC.

Record the response in Logger Pro using a recording frequency of 1000 samples per second (under "Experiment" → "Data Collection"). **NOTE:** Take into account that the Power Amplifier has a gain of 2, so that its output voltage is two times the output voltage of the Function Generator.

The DCDT you are using has a sensitivity of 56 mV/mm mV/V/mm. (Record the value marked on your lab setup).

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Final Report for Lab 6 (Each individual must submit a Final Report)

SHOW ALL YOUR WORK ON THIS AND THE FOLLOWING PAGE. Scan these pages and the requested plots and upload them into the Brightspace Dropbox for Lab 6.

Answer the following for your report:

a) *[3 pts]* What are the values of R, R_1, and V_1?

$R =$ 6Ω $R_1 =$ 452Ω

$V_1 =$ 689E-3V

b) *[1 pts]* From Ohm's law and the voltage you measured (V_1), determine the current I through the resistor R_1.

$I = \frac{V}{R} = \frac{684E\text{-}3V}{458\Omega} = 1.50mA$

$I =$ 1.50mA

c) *[3 pts]* Assuming the electrical circuit of the speaker is composed of a resistor R in series with an inductor L, what is the value of L? How does this compare to the inductance from the speaker manufacturer's specification of 0.817 mH (measured at 1 kHz)?

NOTE: If an inductor and resistor are connected in series, the impedance of the combination is $Z_{system} = R_{total} + Ls$, where s is the Laplace operator. From ENSC 2613 (Circuits), you learned that you can substitute $j\omega$ for s to obtain $R_{total} + j\omega L$. This is a complex number with a magnitude and a phase. The magnitude is $|Z_{system}| = \sqrt{R_{total}{}^2 + \omega^2 L^2}$. Calculate $|Z_{system}|$ using V_{input} (2V RMS) and I (the current) from Part b). Then calculate the value of L using the equation above.

$(R_{total} = R + R_1,\ |Z_{system}| = |\frac{V_{input}}{I}|;\ \omega$ must be in rad/s)

$R_{total}^2 + \omega^2 L^2 = \left|\frac{V_{input}}{I}\right|^2 \rightarrow L = \sqrt{\frac{1}{\omega^2}\left[\left|\frac{V_{in}}{I}\right|^2 - R_{total}^2\right]}$

$L =$ 199.3 mH

From the speaker manufacturer's specifications, the compliance of the system is $1.13\ mm/N$, so $k = 885\ N/m$. We also know that $K_f = 9.62\ N/A$. Assume the back emf constant $K_b = 5.71\ V \cdot \frac{s}{m}$. The effective mass for the speaker is $8.79\ g$; adding the mass of the DVDT core and the circular mounting plate we have roughly $m = 30\ g = 0.030\ kg$. We can also determine from the specifications that $c = 1.532\ N \cdot s/m$.

You should now have all the constants for the system you modeled in the Pre-Lab. <u>You will need to re-do your calculations using the model you derived in the Pre-Lab, with the new parameter values determined in the experiment and given to you in this lab sheet.</u>

Do the following additional items for your report:

d) *[1 pt]* Determine the effective sensitivity for the DCDT in mv/mm (same as V/m)?

56 V/m

e) Prepare a plot of the measured response, beginning from the moment that the speaker leaves its initial position (at $t = 0$) and ending at $t = 0.06\ s$.

f) Prepare a plot of the predicted step response using your reduced model ($L = 0\ H$) with the parameters listed above. (The values for m, R, c, K_f, K_b, k are different than the values used in the Pre-Lab).

g) *[5 pts]* Prepare an overlay of the measured and predicted step responses [parts e) and f)] on a single plot and <u>attach it to this report</u>.

h) Prepare a plot of the predicted step response using the third order model of the system (Equation 3 on p. 373 of the text) using the value of L that you determined in part c).

i) *[5 pts]* Prepare an overlay of the measured and predicted step responses on a single plot and <u>attach it to this report</u>.

j) *[2 pts]* Qualitatively compare the difference between your model and your data. Why is there a difference?

The models and the experiment are off by a factor of 10 that I cannot find.

<u>Final Evaluation</u> (for feedback purposes, will not affect grade)

1) What did you learn from this experiment?

2) What could we do to make the laboratory experiment a better learning experience?

MINIATURE DC OUTPUT LVDT DISPLACEMENT TRANSDUCERS
WITH ACETAL BEARINGS

±1 to ±5 mm
(±0.04 to ±0.20")

LD400 Series

CE

LD400-5, shown actual size.

- High-Output Miniature Transducers
- Acetal Bearings for Precise Motion
- Infinite Resolution
- Rugged, Low-Mass Construction
- Compatible with Standard DC Signal
- Conditioning Modules and Instruments

The LD400 Series miniature DC to DC transducers can measure displacements up to ±5 mm (±0.20") with very high accuracy and infinite resolution. Their free-guided armature incorporates acetal bearings, which provide near-frictionless motion to detect the smallest movement the associated instrumentation is capable of identifying.

These transducers use a precision linear variable differential transformer as the measuring source, along with hybrid ICs, including an oscillator, demodulator, and filter. Together, they make up a self-contained unit that accepts DC input and provides DC output relative to armature position. The unit's high linearity and low mass of moving parts are ideal for applications in civil, mechanical, chemical, and production engineering.

SPECIFICATIONS
ELECTRICAL

Linearity: 0.3% FS
Sensitivity: (mV/V/mm) see chart below (actual output supplied with each unit)
Excitation: 10 to 24 Vdc regulated
Energizing Current at 10 Vdc: LD400-1, 10 mA; LD400-25, 10 mA; LD400-5, 13 mA
Response Time: LD400-1 and LD400-2.5 = 5 ms; LD400-5 = 3 ms
Frequency Response: 50 Hz for -3 dB
Ripple: <1% FS
Thermal Effect: Zero: LD400-1 <0.02% FS/°C; LD400-2.5 and LD400-5 <0.01% FC/°C; sensitivity: <0.025% FC/°C
Compensated Temperature Range: -20 to 80°C (-4 to 176°F)
Operating Temperature Range: -20 to 80°C (-4 to 176°F)
Electrical Connection: 2.9 m (9') shielded, color-coded cable
Sensitivity and Linearity Data: Provided with a transducer output impedance of 2.4 kΩ into a calibration load of 20 kΩ at 20°C (68°F); variations in these parameters will change performance

MECHANICAL

Threaded Core: M2 thread
Core Material: Ni/Fe—Radio Metal 50
Case Material: 400 Series stainless steel
Weight: See chart on next page

CONNECTIONS

Electrical Connections:
- **Red:** + Excitation
- **Blue:** – Excitation
- **White:** + Signal*
- **Green:** – Signal
- **Yellow:** No connection

** White and red in phase for positive inward displacement*

To Order *Visit omega.com/ld400 for Pricing and Details*

MODEL NO.	STROKE	SENSITIVITY	COMPATIBLE METERS
LD400-1	±1.0 mm (0.06")	75 mV/V/mm	DP41-S, DP25B-S
LD400-2.5	±2.5 mm (0.10")	75 mV/V/mm	DP41-S, DP25B-S
LD400-5	±5.0 mm (0.20")	54 mV/V/mm	DP41-S, DP25B-S

Ordering Example: LD400-5, stroke of ±5 mm.

MINIATURE DC DISPLACEMENT TRANSDUCERS

DP25B-S.

DP41-S.

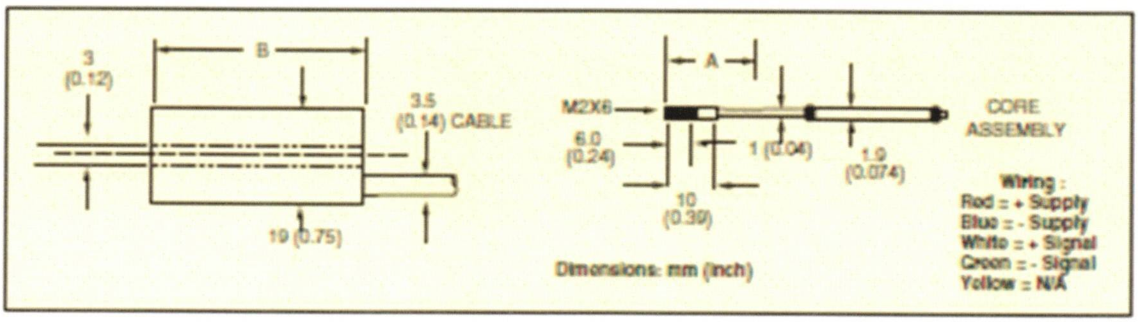
Both meters shown slightly smaller than actual size.

LD400-5, shown actual size.

DISPLACEMENT J

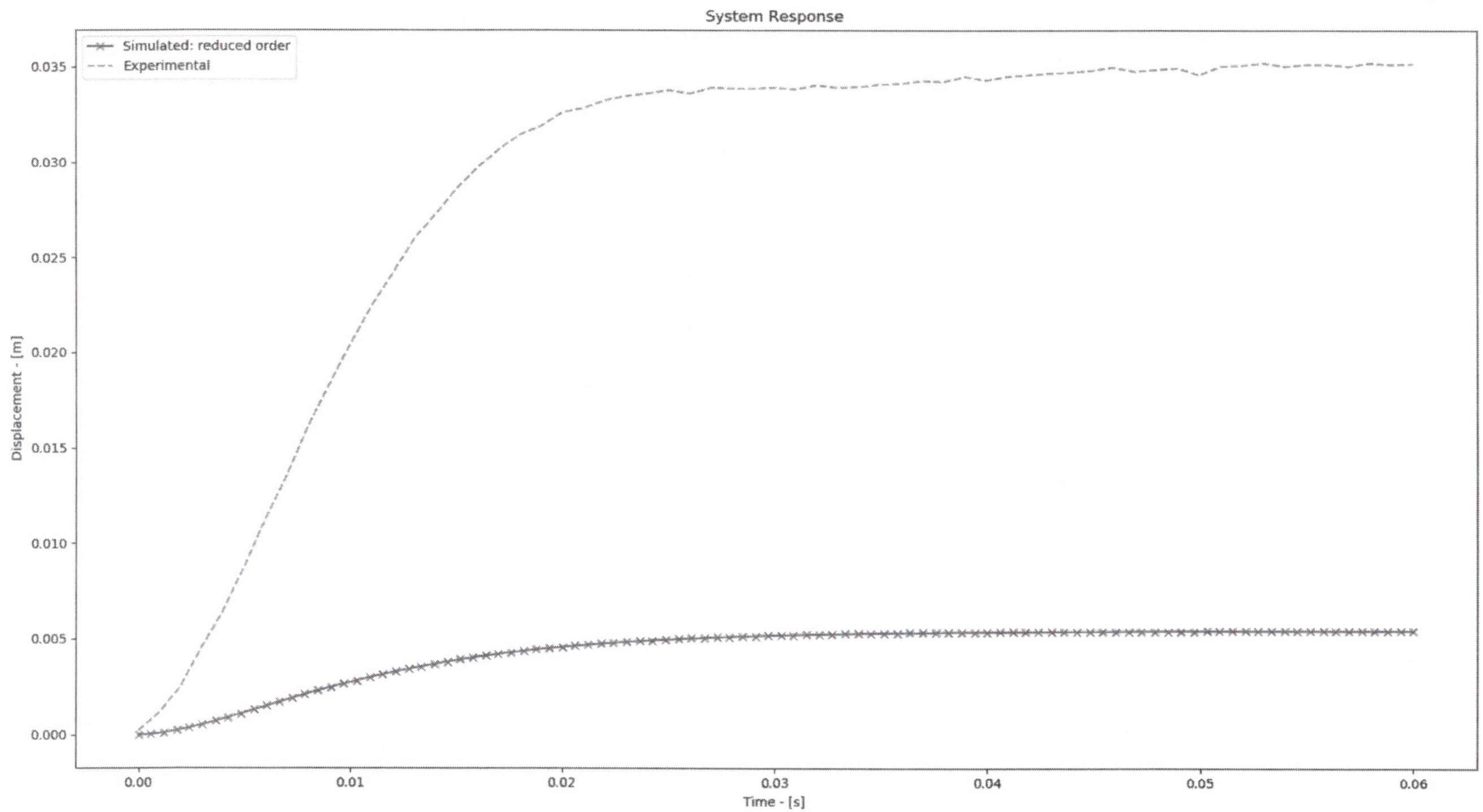
COMPATIBLE INSTRUMENTS, VISIT OMEGA.COM

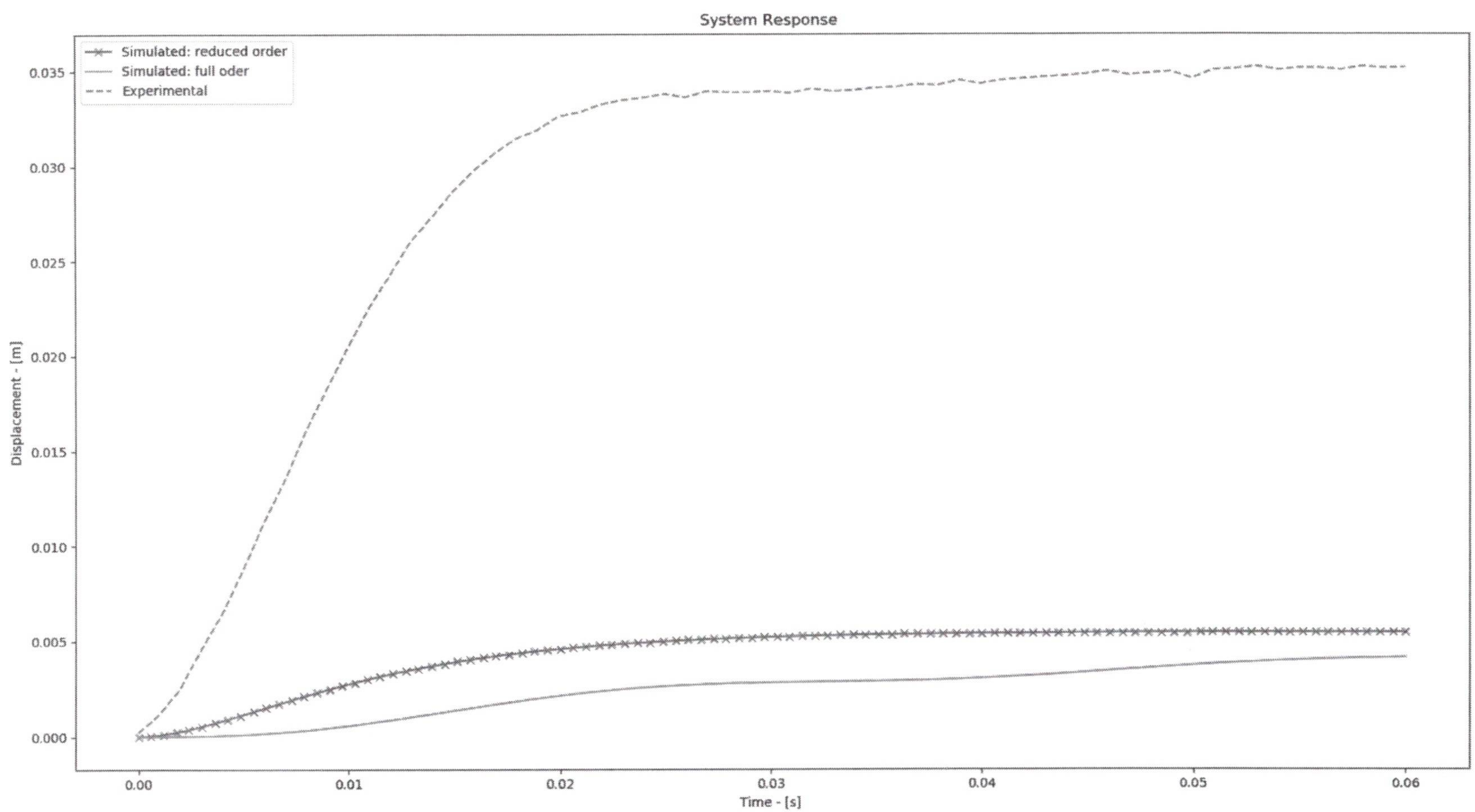
MODEL NO.	DESCRIPTION
DP25B-S	Ratiometric voltage and current input meter with excitation
DP41-S	115 Vac powered strain gage indicator



MODEL NO.	LINEAR STROKE mm (inch)	DIMENSIONS*: mm (inch)		WEIGHT g (oz)	
		A	B	BODY	CORE (GUIDED)
LD400-1	±1.0 (0.04)	21.5 (0.85)	37 (1.46)	26 (1.02)	1.0 (0.04)
LD400-2.5	±2.5 (0.10)	21.5 (0.85)	37 (1.46)	26 (1.02)	1.0 (0.04)
LD400-5	±5.0 (0.20)	20.5 (0.81)	43 (1.69)	30 (1.18)	1.2 (0.04)

* At electrical zero.


System Response
Simulated: reduced order
Experimental
Displacement - [m]
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0.00
0.01
0.02
0.03
0.04
0.05
0.06
Time - [s]


System Response
Simulated: reduced order
Simulated: full oder
Experimental
Displacement - [m]
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0.00
0.01
0.02
0.03
0.04
0.05
0.06
Time - [s]