LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Document Type LIGO-T1300530-v1, May 18th, 2011

aLIGO CryoPump Baffle Suspension, Ring-down Measurements

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1 Introduction

This document report the most significant measurements done to characterize the eddy current damper for the rigid body modes of the CryoPump (CPB) Baffle.

2 Setup

- Suspension: CPB suspension prototype a.k.a. first article suspension with glazed baffle suspended to the frame used to assemble and balance the baffle.
- Payload: Nominal + one Teac accelerometer
  - Damper: not in final configuration. The magnet are in the old configuration i.e. placed on the outer barrel of the baffle. This is very different from final configuration.
  - Number of magnets per damper: 4 or 8 (see pictures),
  - Gap: 1/10" = 2.5 mm
- Excitation: provided manually by displacing the baffle from its equilibrium position,
- Sensors TEAC Amplifier and accelerometer TEAC P/N 710
- DAQ: Tektronix digital scope

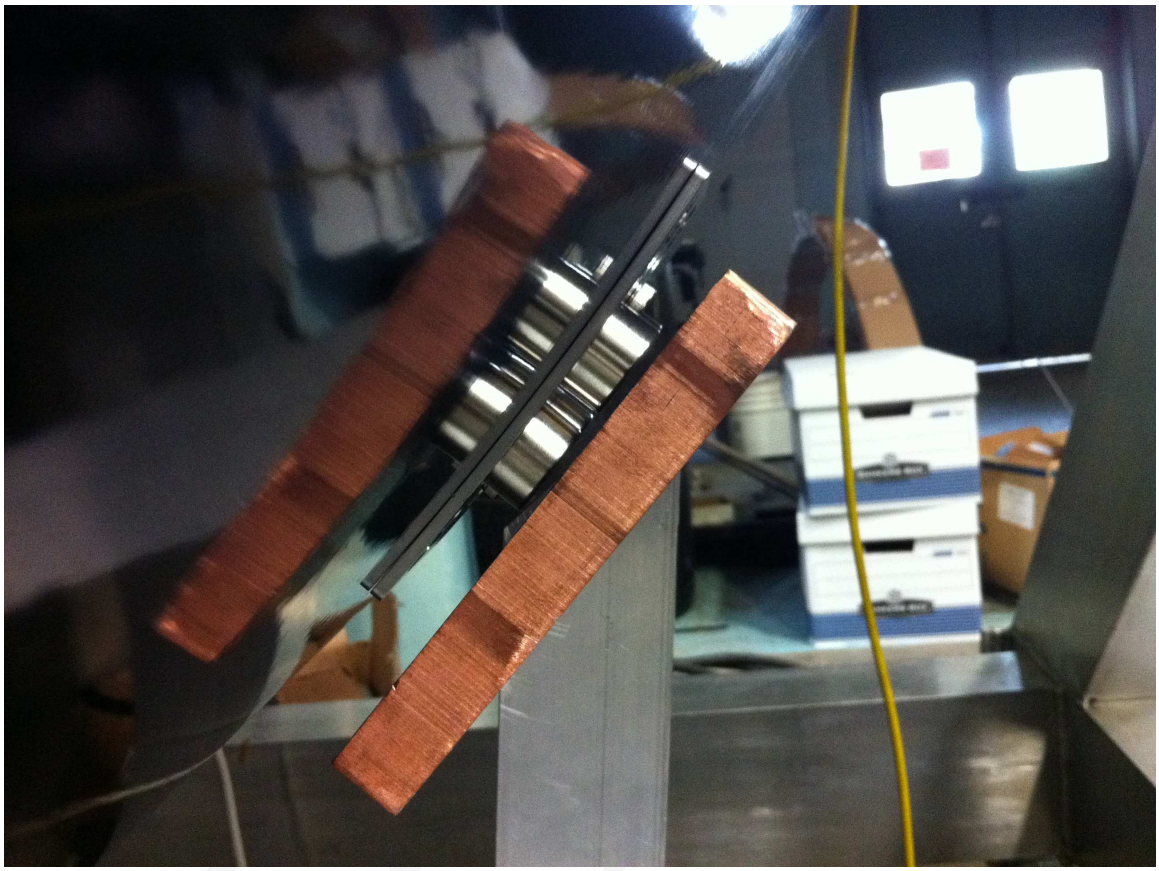
3 Conclusion

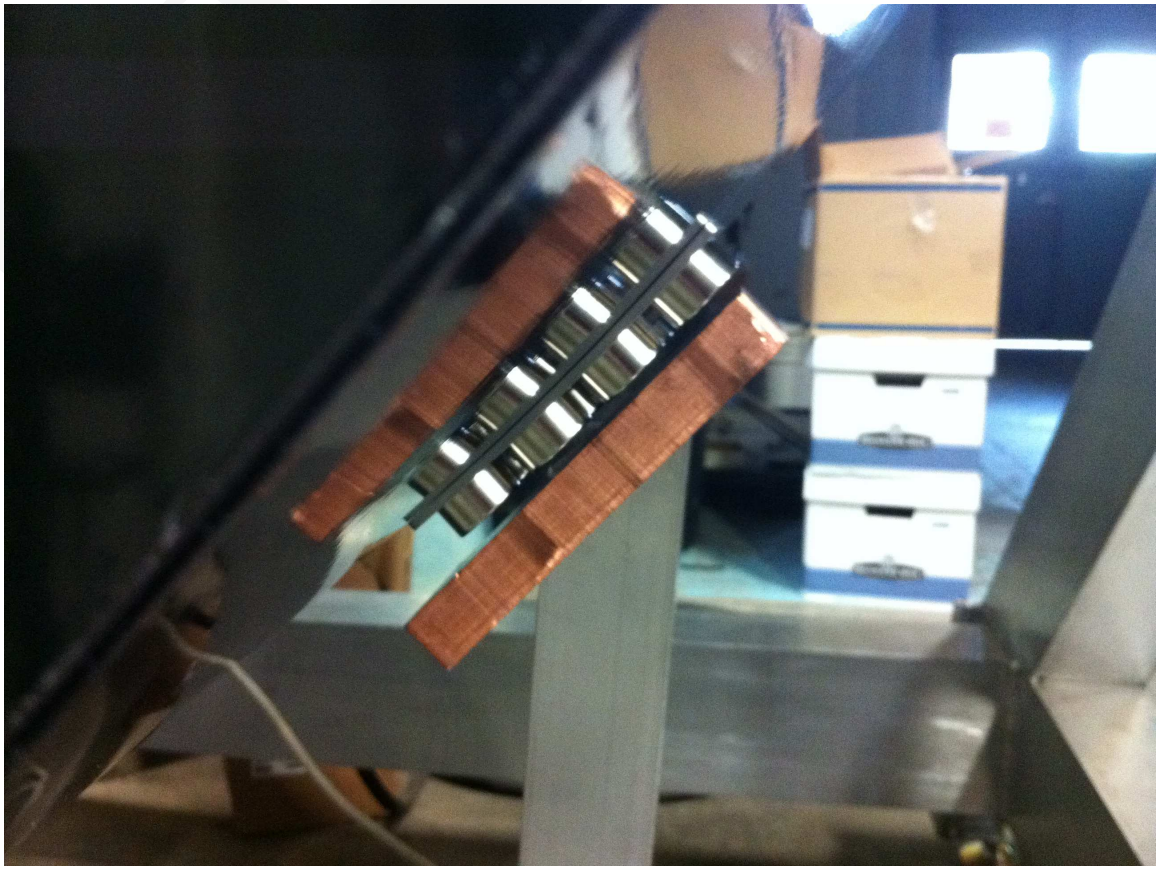
Quality factors for all measured modes are well below the required value of 100 using 4 magnets per damper. The least dumped mode (roll mode) has a quality factor of about 53 which has the highest resonant frequency of 3.04 Hz. All the difference plots of modes that involve the blades show a large systematic error which can be explained by the expected non linear behavior of the thick blades used to suspend the baffle.

Measurements show that the heavy baffle can be damped sufficiently well using a total of 8 magnets, 4 per damper. The different topology of the final damper with the same number of magnets but facing vertical copper plates should provide similar performance in terms of quality factors. Vertical modes damping should improve and translational modes ortogonal to the copper plates should become worst but it is very unlikely that those modes will have Q values above 100.

4 Pictures

Pictures below show the configuration of the damper with 4 of 8 magnets





A Ring-down Measurements

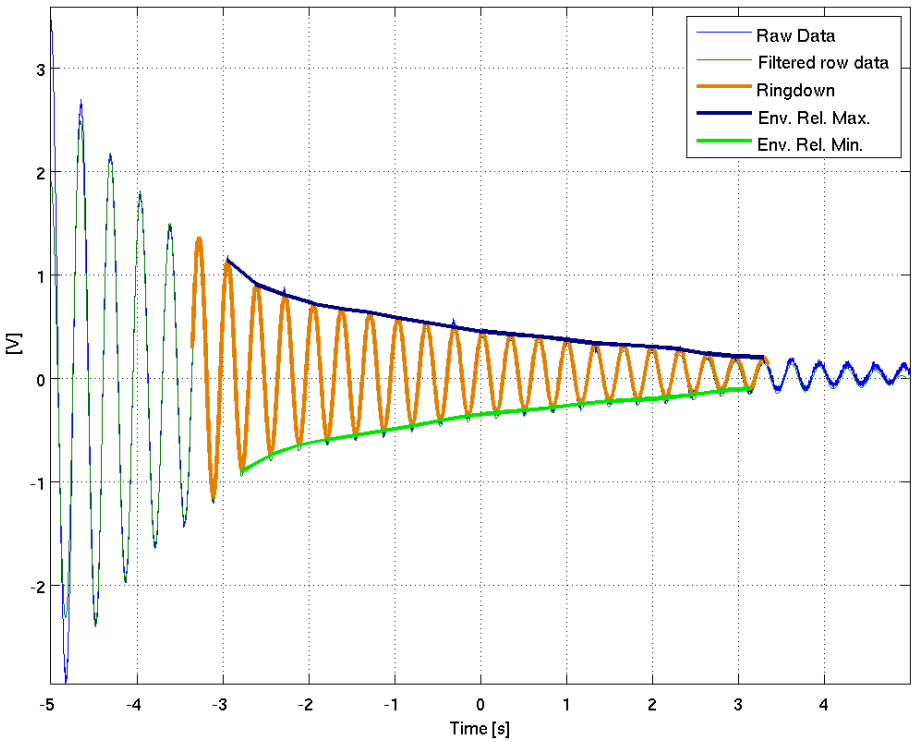
Date: Monday May 18th, 2011

CPB Suspension: Ringdown Roll Mode

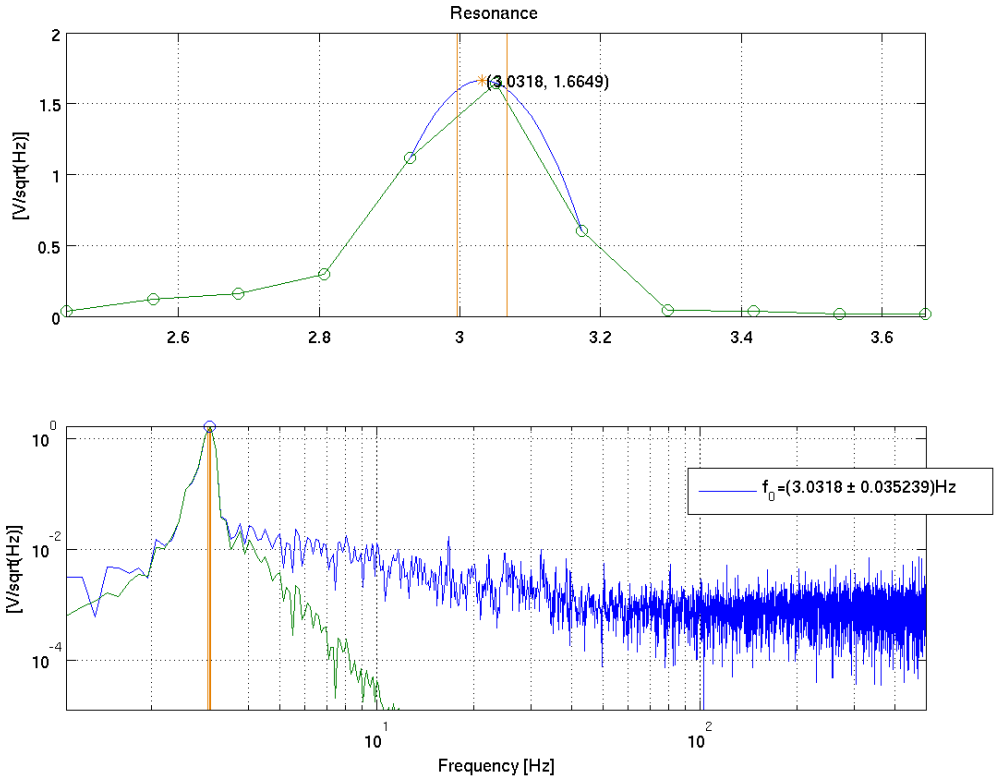
Cryogenic Pump Baffle (CPB) suspension ring-down measurement
Number of magnets: 8
Copper plates: 2
Direction: Y , horizontal parallel to laser beam axis

Exponential RingDown Analysis

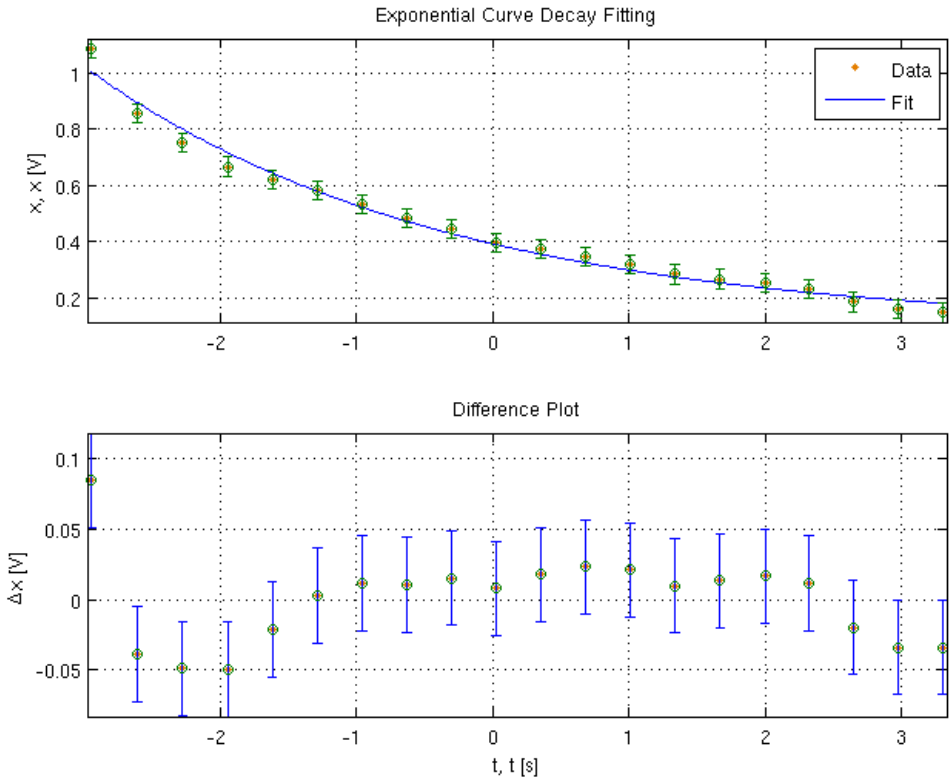
Raw Data and Envelopes Calculation



First and last 5 periods not used because of the systematic introduced by the aggressive filtering
Resonant Frequency Determination



Resonant frequency vertical mode.
Fit of the Envelope Maxima



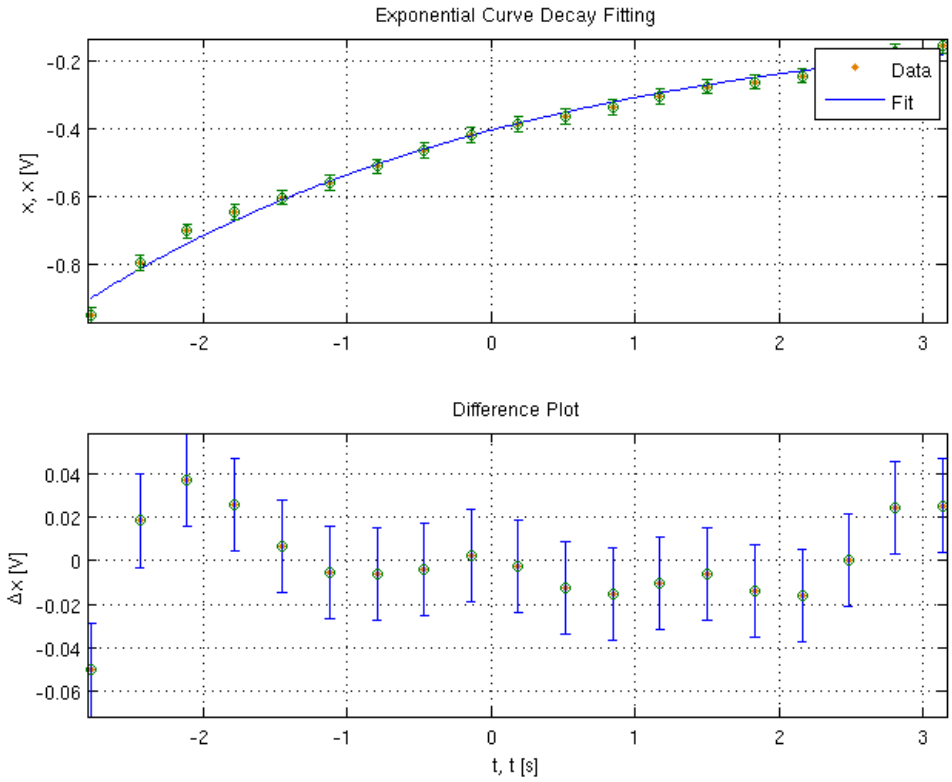
No clear systematic in the difference plot
Fit of the Envelope Maxima

Fitting Function:
 x(t)=x_0 exp(-x/tau)+x_1

Parameters:
     x_0 = (0.2939 +- 0.0437)V
     tau = (2.622 +- 0.290)s

```
     x_1 = ( 0.0990 +- 0.0378 )V

Degrees of Freedom, v = 17

Reduced ChiSquare X^2/v = 0.999969

Standard Deviation Residuals STDR = 0.0317658 V

Correlation Matrix:
                     x_0  1.00
                     tau  0.98  1.00
                     x_1 -0.98 -0.94  1.00

Comments:
Reduced chi square value set ad hoc, uncertainties are reliable only
if there are no systematic errors and noise is purely gaussian.
```

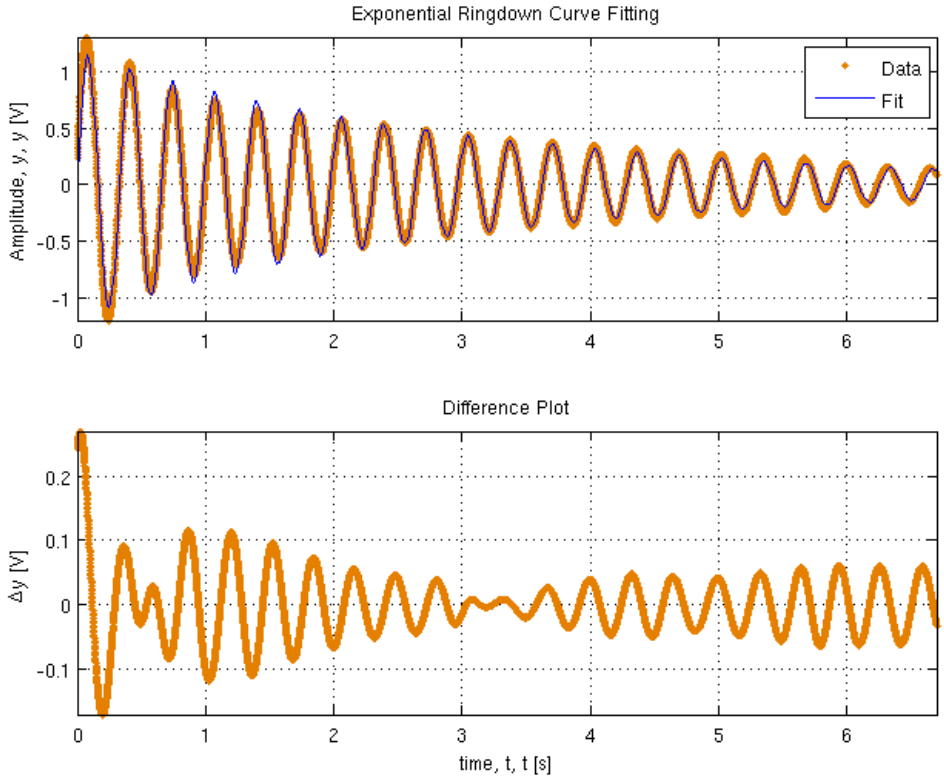
Fit of the Envelope Minima



No clear systematic in the difference plot
Fit of the Envelope Minima

```
Fitting Function:
 x(t)=x_0 exp(-x/tau)+x_1

Parameters:
     x_0 = ( -0.3572 +- 0.0426 )V
     tau = ( 3.190 +- 0.315 )s
     x_1 = ( -0.0457 +- 0.0381 )V

Degrees of Freedom, v = 16

Reduced ChiSquare X^2/v = 0.999999

Standard Deviation Residuals STDR = 0.0201317 V

Correlation Matrix:
                     x_0  1.00
                     tau -0.98  1.00
                     x_1 -0.99  0.96  1.00

Comments:
Reduced chi square value set ad hoc, uncertainties are reliable only
if there are no systematic errors and noise is purely gaussian.
```

Fit of the RingDown



Clear systematic in the difference plot
Fit of the RingDown

Fitting Function:
 y(t)=Y exp(-t/tau) sin(w t+phi)+Y0

Parameters:
```
                      Y = -1.17649 V
                    tau = 3.08136 s
                      w = 19.0735 rad/2
                    phi = -3.14355 rad
                     Y0 = 0.00197043 V
```

Degrees of Freedom, v = 6696

Standard Deviation Residuals STDR = 0.055072 V

Correlation Matrix:
```
                       Y  1.00
                     tau  0.74  1.00
                       w -0.03 -0.02  1.00
                     phi  0.04  0.03 -0.74  1.00
                      Y0  0.03  0.02 -0.01  0.00  1.00
```

Comments:
Reduced chi square value set ad hoc, uncertainties are reliable only
if there are no systematic errors and noise is purely gaussian.
Parameters' uncertainties not printed because data point uncertainties are not provided.

Final analysis

FTT   : Frequency mode f(1) = (3.0318 +- 0.0352)Hz
Zero Crossing: Frequency mode f(1) = (3.045 +- 0.218)Hz
Ring down fit: Frequency mode f(1) = (3.035646 +- 0.000203)Hz

#	tau [s]	stau [s]	Q [#]	sQ [#]
Maxima Env.	2.6218194e+00	2.8960914e-01	2.4971620e+01	9.1654432e-01
Minima Env.	3.1902968e+00	3.1549794e-01	3.0386105e+01	9.9732931e-01
Ringdown	3.0813579e+00	1.2084405e-02	2.9348513e+01	1.1703418e-01
Avg	3.0807197e+00	1.2065067e-02	2.9293103e+01	1.1531299e-01

Comments

Quality factor measurement seems reliable. Quality factor is on the low side and certainly below the nominal requirement (Q<100)
Number of magnet can be reduced probably down to a factor 2 by increasing the copper plate thicknessand maintaining a quite low quality factor

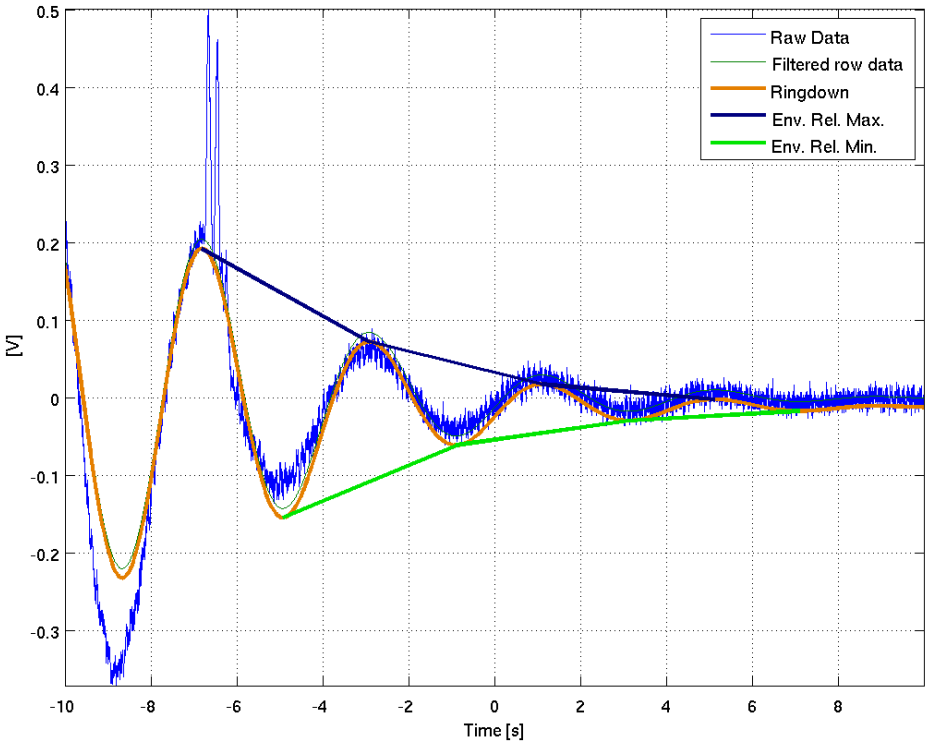
Date: Monday May 18th, 2011

CPB Suspension: Ringdown Vertical Mode

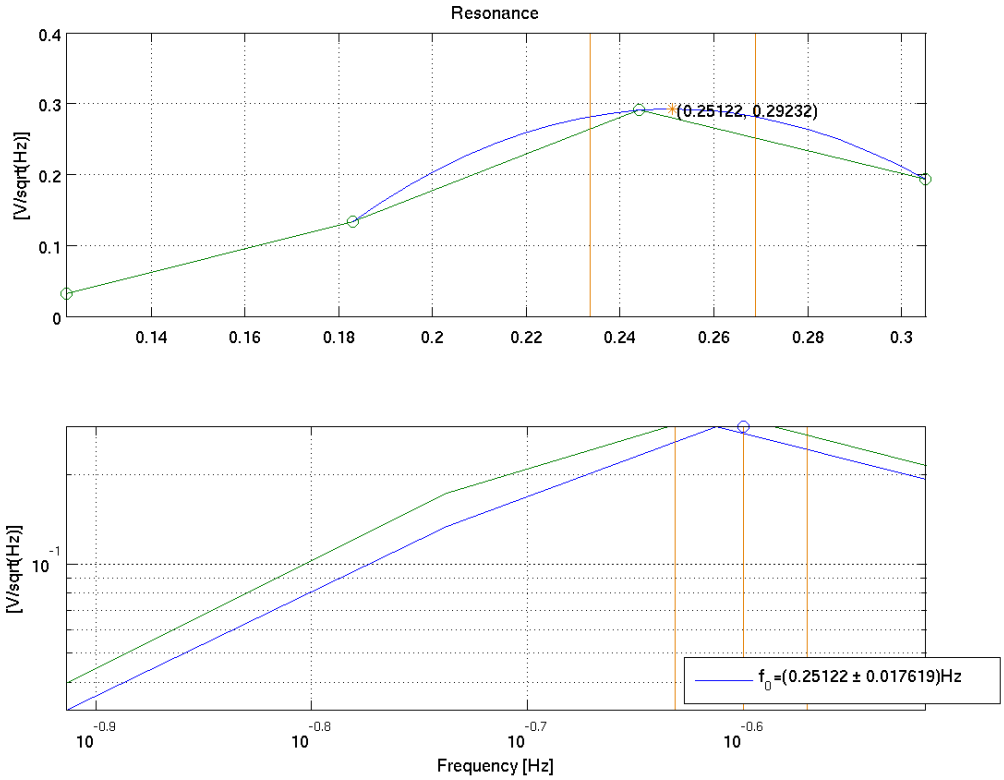
Cryogenic Pump Baffle (CPB) suspension ring-down measurement
Number of magnets: 8
Copper plates: 2
Direction: Y , horizontal parallel to laser beam axis

Exponential RingDown Analysis

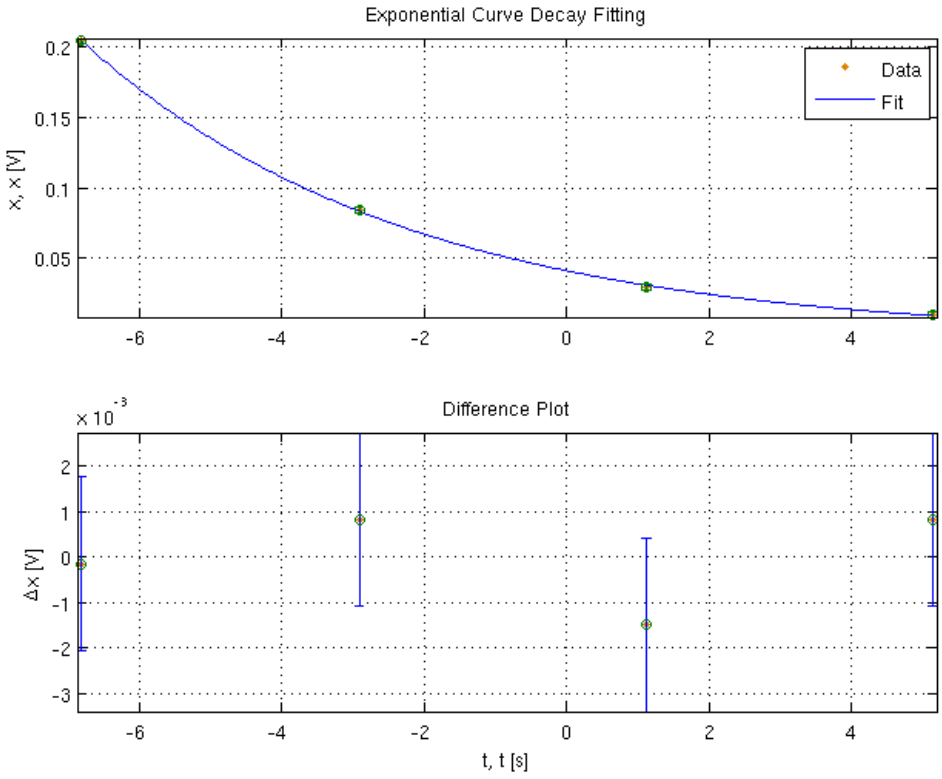
Raw Data and Envelopes Calculation



First and last 0 periods not used because of the systematic introduced by the aggressive filtering
Resonant Frequency Determination



Resonant frequency vertical mode.
Fit of the Envelope Maxima



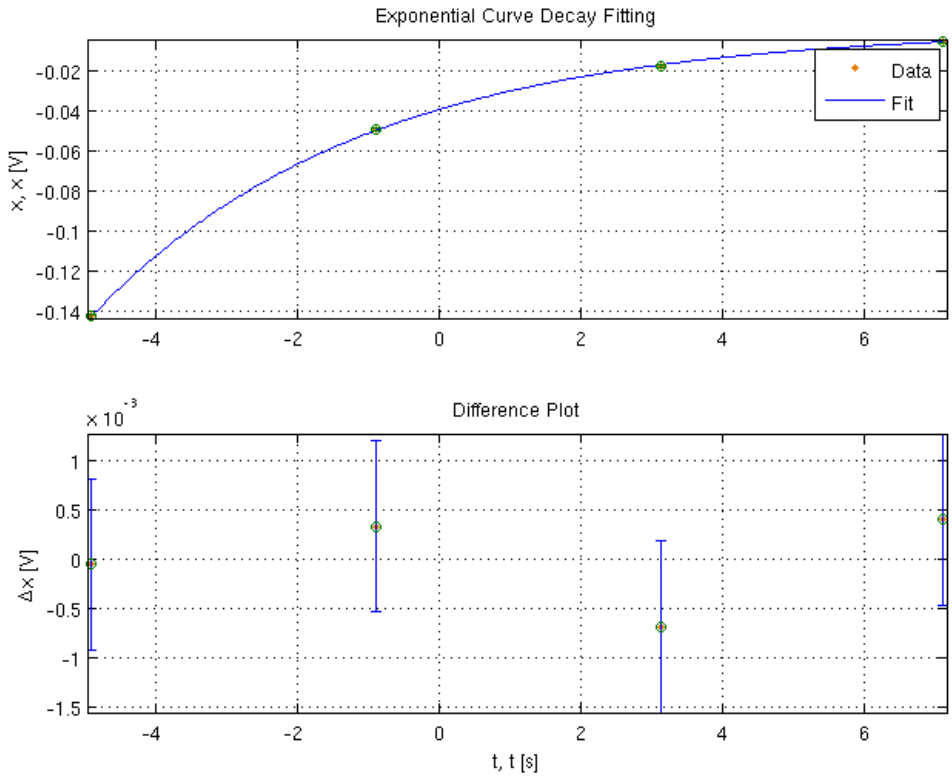
No clear systematic in the difference plot
Fit of the Envelope Maxima

Fitting Function:
x(t)=x_0 exp(-x/tau)+x_1

Parameters:
x_0 = (0.04709 +- 0.00377)V
tau = (4.550 +- 0.204)s

```
     x_1 = ( -5.98 +- 3.41 )x10^-3 V

Degrees of Freedom, v = 1

Reduced ChiSquare X^2/v = 1

Standard Deviation Residuals STDR = 0.00109888 V

Correlation Matrix:
                     x_0  1.00
                     tau  0.99  1.00
                     x_1 -0.94 -0.90  1.00

Comments:
Reduced chi square value set ad hoc, uncertainties are reliable only
if there are no systematic errors and noise is purely gaussian.
```

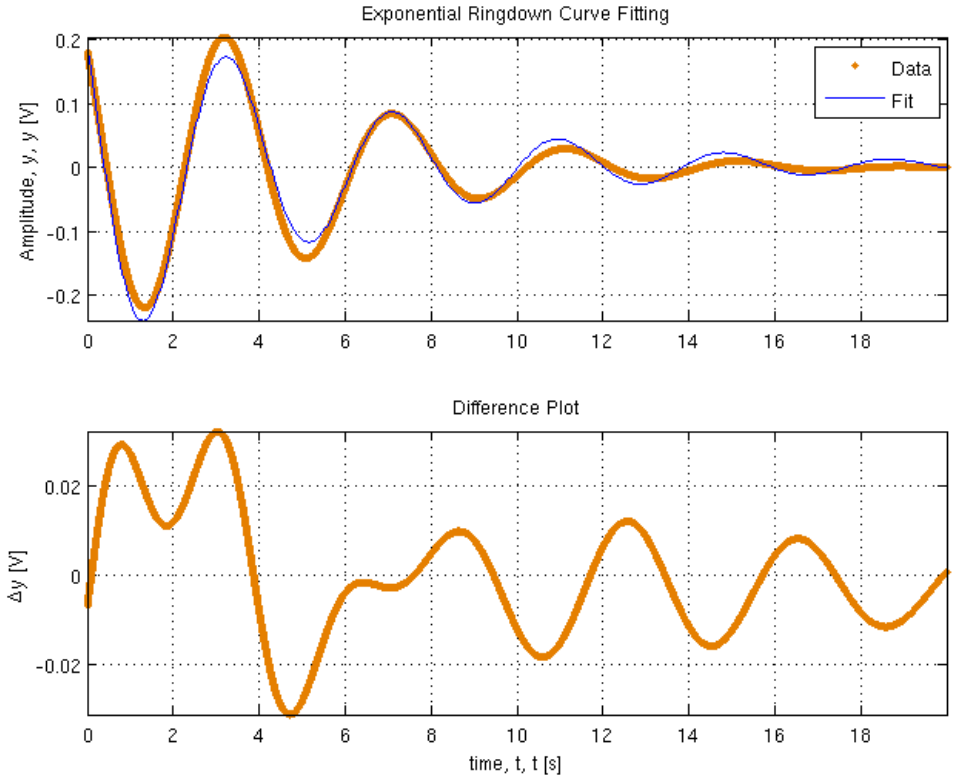
Fit of the Envelope Minima




```
No clear systematic in the difference plot
```
Fit of the Envelope Minima

```
Fitting Function:
 x(t)=x_0 exp(-x/tau)+x_1

Parameters:
     x_0 = ( -0.04013 +- 0.00167 )V
     tau = ( 3.859 +- 0.106 )s
     x_1 = ( 1.04 +- 1.24 )x10^-3 V

Degrees of Freedom, v = 1

Reduced ChiSquare X^2/v = 0.999944

Standard Deviation Residuals STDR = 0.000498578 V

Correlation Matrix:
                     x_0  1.00
                     tau -0.98  1.00
                     x_1 -0.92  0.87  1.00

Comments:
Reduced chi square value set ad hoc, uncertainties are reliable only
if there are no systematic errors and noise is purely gaussian.
```

Fit of the RingDown



Clear systematic in the difference plot
Fit of the RingDown

Fitting Function:
y(t)=Y exp(-t/tau) sin(w t+phi)+Y0

Parameters:

Y	-0.309334 V
tau	5.46999 s
w	1.62699 rad/2
phi	-0.643905 rad
Y0	0.00280926 V

Degrees of Freedom, v = 9995

Standard Deviation Residuals STDR = 0.0140242 V

Correlation Matrix:

Y	1.00				
tau	0.76	1.00			
w	0.01	0.02	1.00		
phi	-0.00	-0.01	-0.68	1.00	
Y0	-0.13	-0.10	-0.08	0.11	1.00

Comments:
Reduced chi square value set ad hoc, uncertainties are reliable only
if there are no systematic errors and noise is purely gaussian.
Parameters' uncertainties not printed because data point uncertainties are not provided.

Final analysis

FTT : Frequency mode f(1) = (0.2512 +- 0.0176)Hz
Zero Crossing: Frequency mode f(1) = (0.2459 +- 0.0665)Hz
Ring down fit: Frequency mode f(1) = (0.2589428 +- 0.0000982)Hz

#	tau [s]	stau [s]	Q [#]	sQ [#]
Maxima Env.	4.5496009e+00	2.0429946e-01	3.5906166e+00	6.4420814e-01
Minima Env.	3.8589608e+00	1.0561316e-01	3.0455526e+00	3.3637908e-01
Ringdown	5.4699882e+00	2.0795870e-02	4.3170007e+00	8.5628375e-02
Avg	5.4013608e+00	2.0303071e-02	4.2290315e+00	8.2301951e-02

Comments

Quality factor measurement seems reliable. Quality factor is on the low side and certainly below the nominal requirement (Q<100)
Number of magnet can be reduced probably down to a factor 2 by increasing the copper plate thicknessand maintaining a quite low quality factor

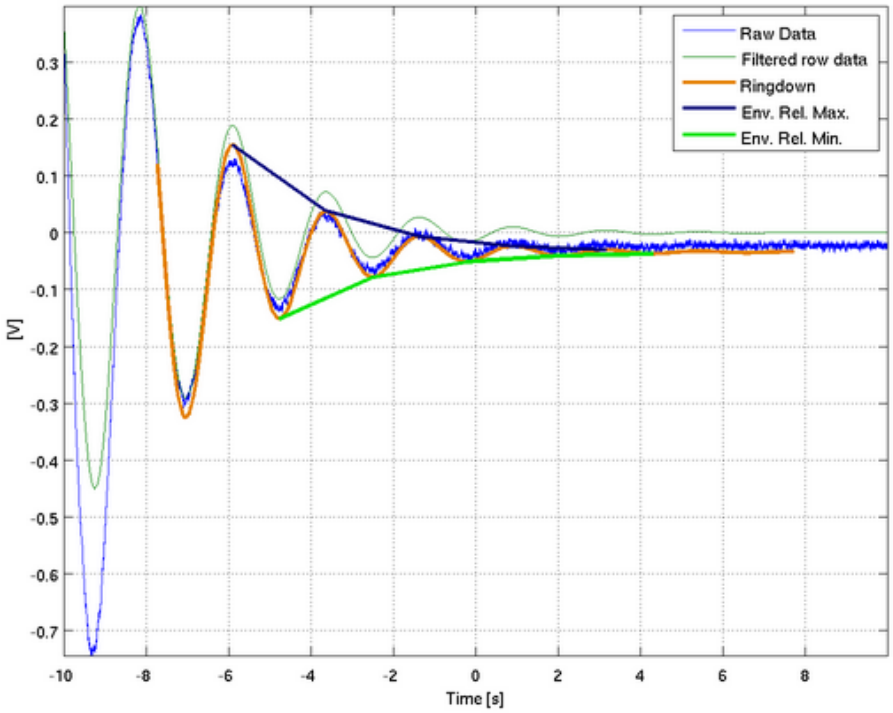
Date: Monday May 18th, 2011

CPB Suspension: Ringdown Vertical Mode

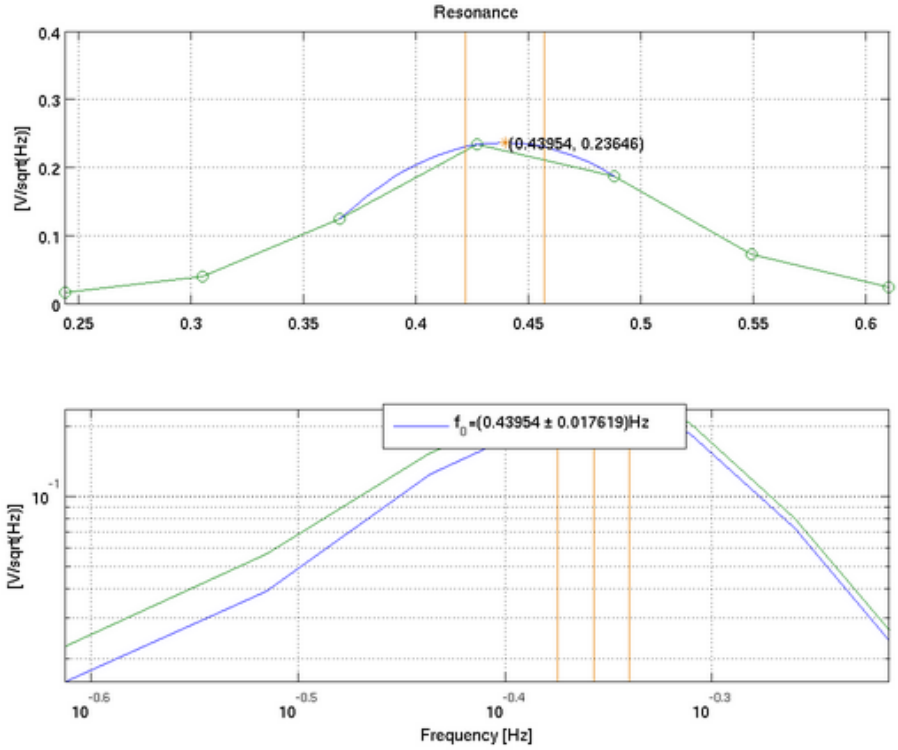
Cryogenic Pump Baffle (CPB) suspension ring-down measurement
Number of magnets: 8
Copper plates: 2
Direction: Y , horizontal parallel to laser beam axis

Exponential RingDown Analysis

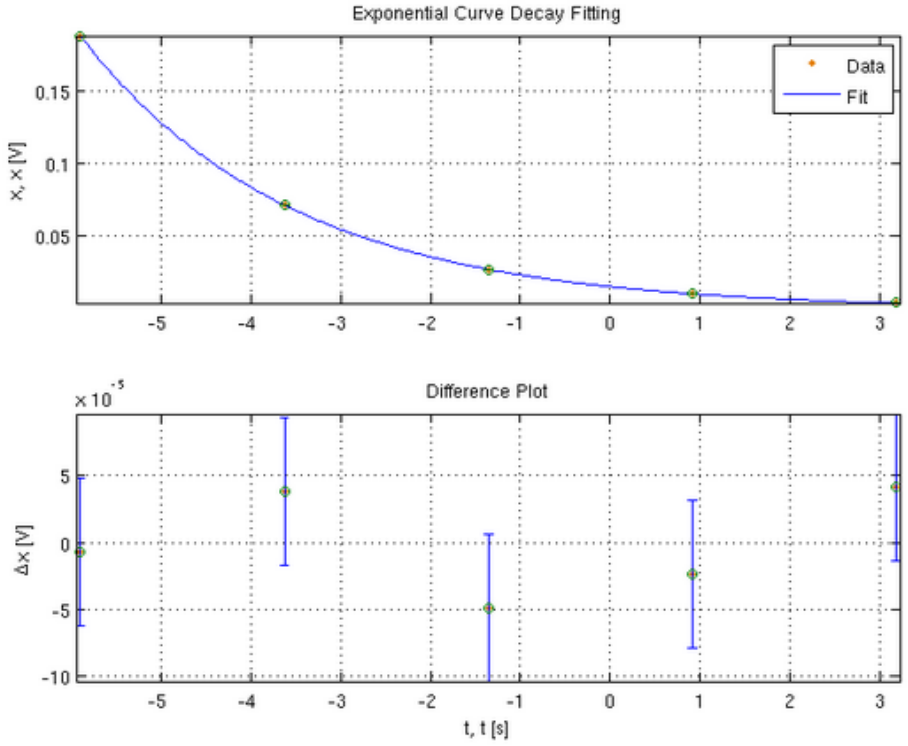
Raw Data and Envelopes Calculation



First and last 1 periods not used because of the systematic introduced by the aggressive filtering
Resonant Frequency Determination



Resonant frequency vertical mode.
Fit of the Envelope Maxima



No clear systematic in the difference plot
Fit of the Envelope Maxima

Fitting Function:
 x(t)=x_0 exp(-x/tau)+x_1

Parameters:
     x_0 = (0.0152646 +- 0.0000436)V
     tau = (2.34528 +- 0.00250)s
     x_1 = (3.86 +- 5.56)x10^-5 V

Degrees of Freedom, v = 2

Reduced ChiSquare X^2/v = 1

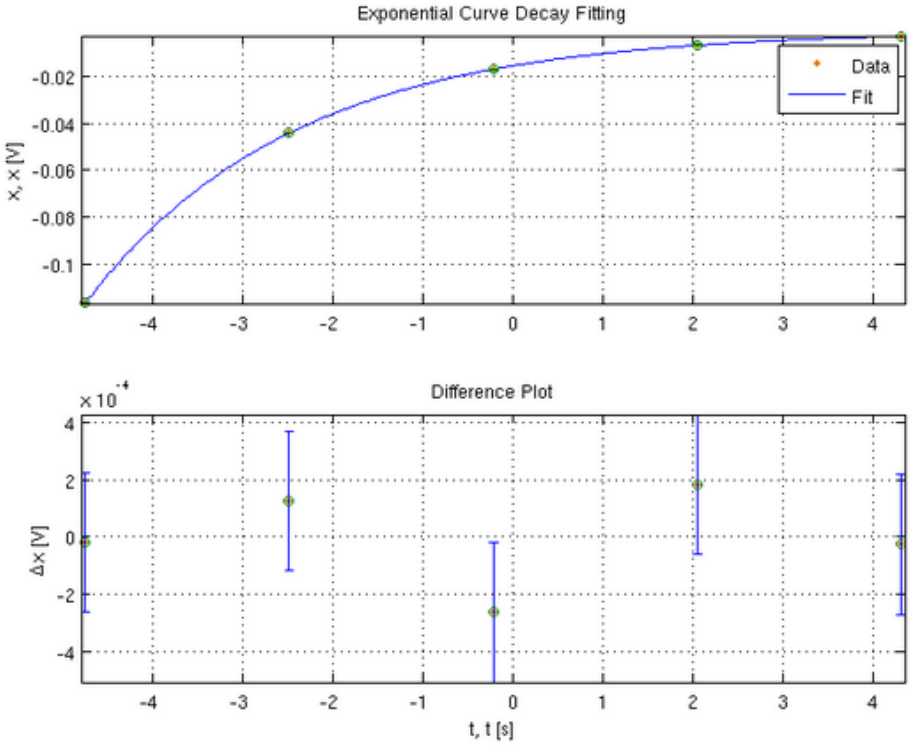
Standard Deviation Residuals STDR = 3.88457e-05 V

Correlation Matrix:

x_0	1.00		
tau	0.99	1.00	
x_1	-0.85	-0.81	1.00

Comments:
Reduced chi square value set ad hoc, uncertainties are reliable only
if there are no systematic errors and noise is purely gaussian.

Fit of the Envelope Minima



No clear systematic in the difference plot
Fit of the Envelope Minima

Fitting Function:
x(t)=x_0 exp(-x/tau)+x_1

Parameters:
x_0 = (-0.014874 +- 0.000254)V
tau = (2.3131 +- 0.0178)s
x_1 = (-3.49 +- 2.44)x10^-4 V

Degrees of Freedom, v = 2

Reduced ChiSquare X^2/v = 1

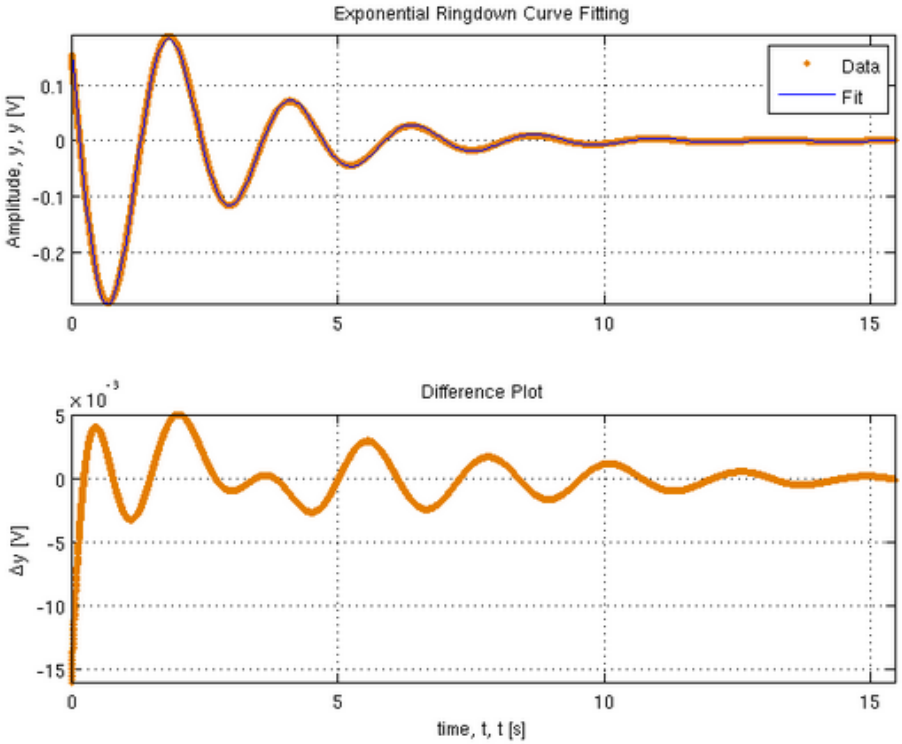
Standard Deviation Residuals STDR = 0.000173023 V

Correlation Matrix:

x_0	1.00		
tau	-0.99	1.00	
x_1	-0.85	0.80	1.00

Comments:
Reduced chi square value set ad hoc, uncertainties are reliable only
if there are no systematic errors and noise is purely gaussian.

Fit of the RingDown



Clear systematic in the difference plot
Fit of the RingDown

Fitting Function:
 y(t)=Y exp(-t/tau) sin(w t+phi)+Y0

Parameters:
```
                      Y = -0.390286 V
                    tau = 2.46436 s
                      w = 2.75025 rad/2
                    phi = -0.451691 rad
                     Y0 = 9.28273e-05 V
```

Degrees of Freedom, v = 7720

Standard Deviation Residuals STDR = 0.00192195 V

Correlation Matrix:
```
                       Y  1.00
                     tau  0.76  1.00
                       w -0.04 -0.03  1.00
                     phi  0.09  0.06 -0.66  1.00
                      Y0 -0.13 -0.09 -0.07  0.09  1.00
```

Comments:
Reduced chi square value set ad hoc, uncertainties are reliable only
if there are no systematic errors and noise is purely gaussian.
Parameters' uncertainties not printed because data point uncertainties are not provided.

Final analysis

FTT   : Frequency mode f(1) = (0.4395 +- 0.0176)Hz
Zero Crossing: Frequency mode f(1) = (0.431 +- 0.174)Hz
Ring down fit: Frequency mode f(1) = (0.4377159 +- 0.0000344)Hz

#	tau [s]	stau [s]	Q [#]	sQ [#]
Maxima Env.	2.3452840e+00	2.5046031e-03	3.2384959e+00	5.5909220e-02
Minima Env.	2.3130621e+00	1.7772291e-02	3.1940022e+00	7.8621152e-02
Ringdown	2.4643591e+00	1.5166480e-03	3.4029212e+00	5.5557454e-02
Avg	2.4317784e+00	1.2938882e-03	3.2956806e+00	3.5230702e-02

Comments

Quality factor measurement seems reliable. Quality factor is on the low side and certainly below the nominal requirement (Q<100)
umber of magnet can be reduced probably down to a factor 2 by increasing the copper plate thickness and still maintaining a quite low quality factor

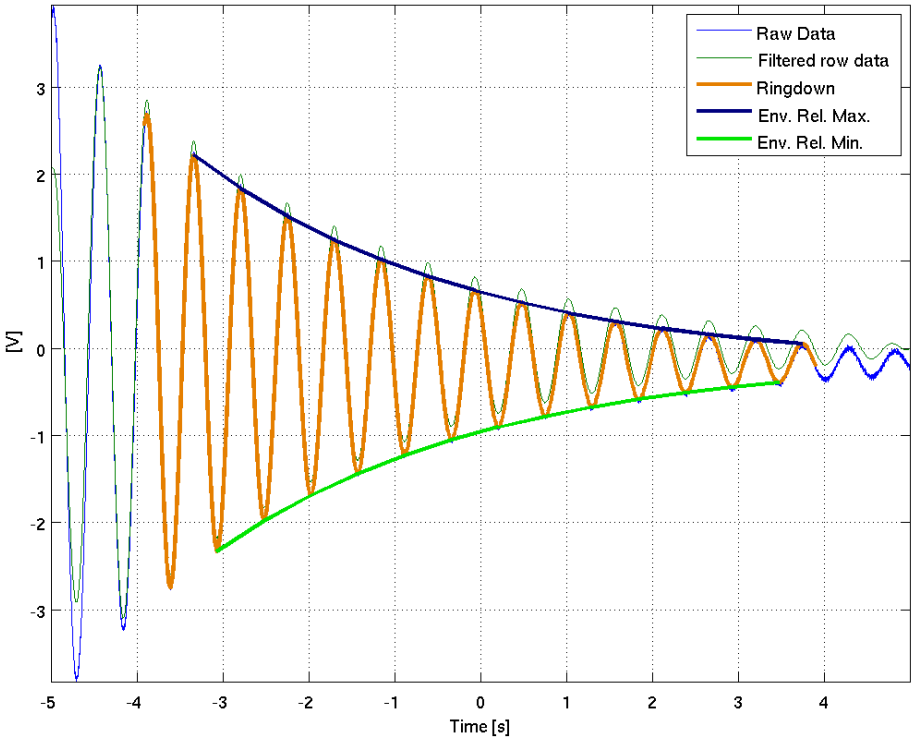
Date: Monday May 18th, 2011

CPB Suspension: Ringdown Vertical Mode

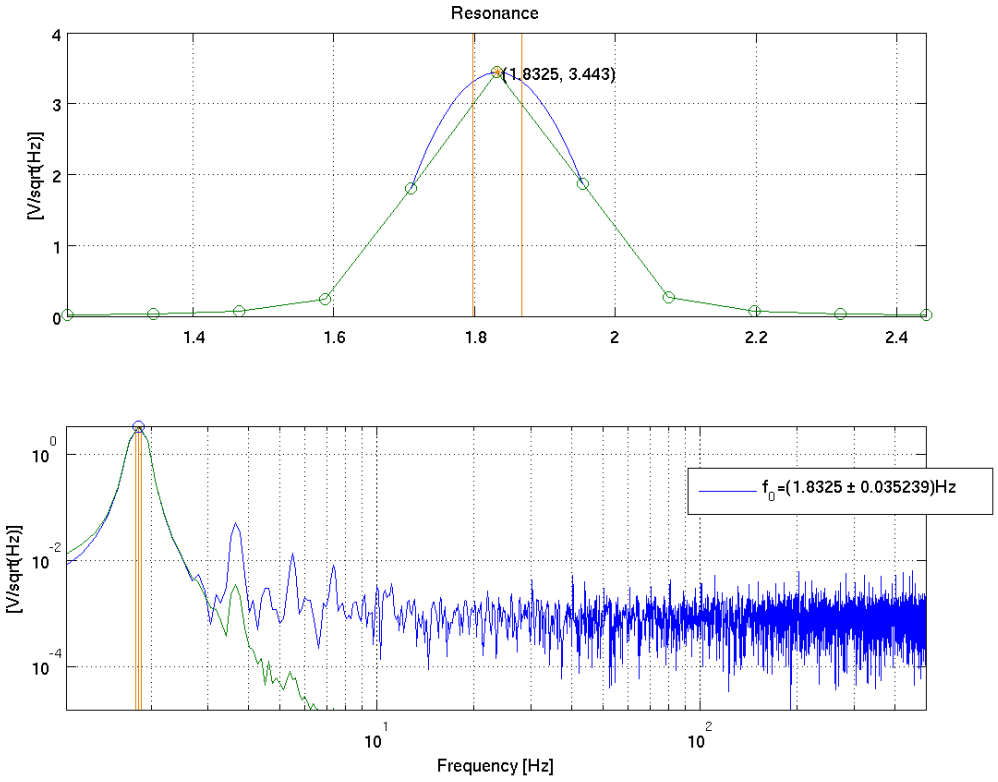
Cryogenic Pump Baffle (CPB) suspension ring-down measurement
Number of magnets: 8
Copper plates: 8
Direction: Z , vertical orthogonal to beam axis

Exponential RingDown Analysis

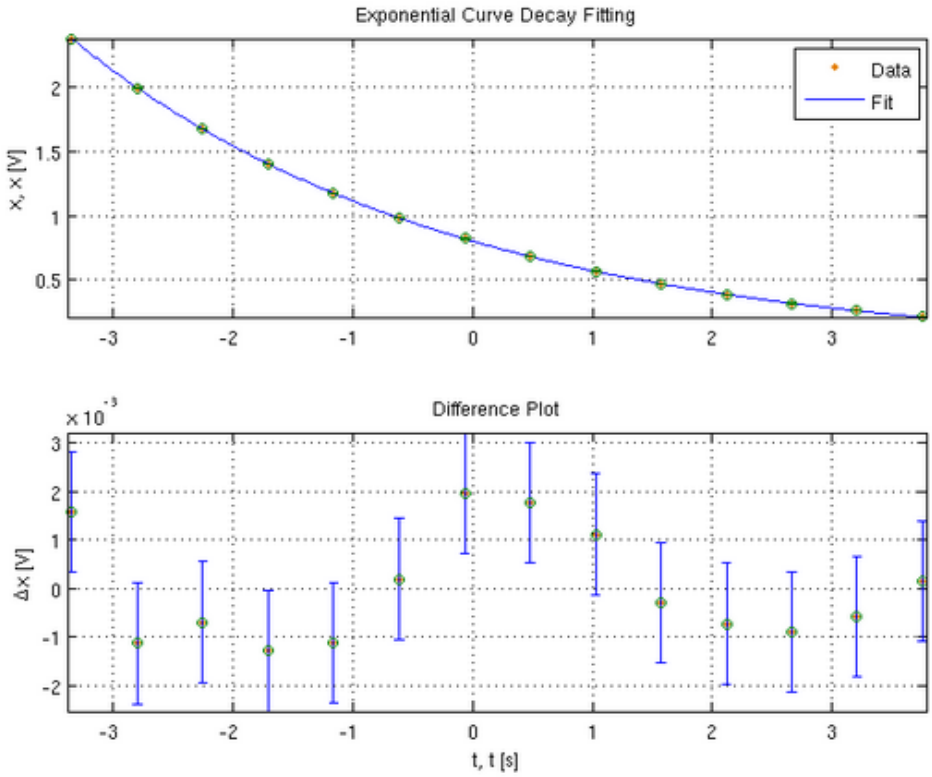
Raw Data and Envelopes Calculation



First and last 2 periods not used because of the systematic introduced by the aggressive filtering
Resonant Frequency Determination



Resonant frequency vertical mode.
Fit of the Envelope Maxima



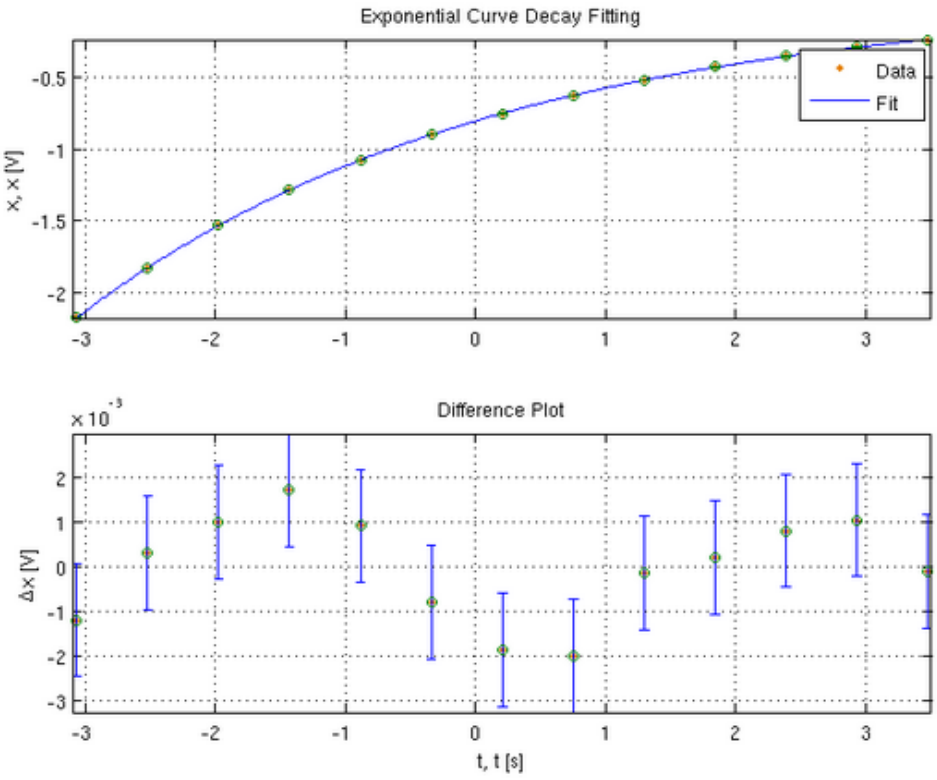
No clear systematic in the difference plot
Fit of the Envelope Maxima

Fitting Function:
 x(t)=x_0 exp(-x/tau)+x_1

Parameters:
     x_0 = (0.85861 +- 0.00212)V
     tau = (3.20090 +- 0.00603)s

```
     x_1 = ( -0.05589 +- 0.00185 )V

Degrees of Freedom, v = 11

Reduced ChiSquare X^2/v = 1

Standard Deviation Residuals STDR = 0.00115074 V

Correlation Matrix:
                      x_0  1.00
                      tau  0.98  1.00
                      x_1 -0.98 -0.94  1.00

Comments:
Reduced chi square value set ad hoc, uncertainties are reliable only
if there are no systematic errors and noise is purely gaussian.
```

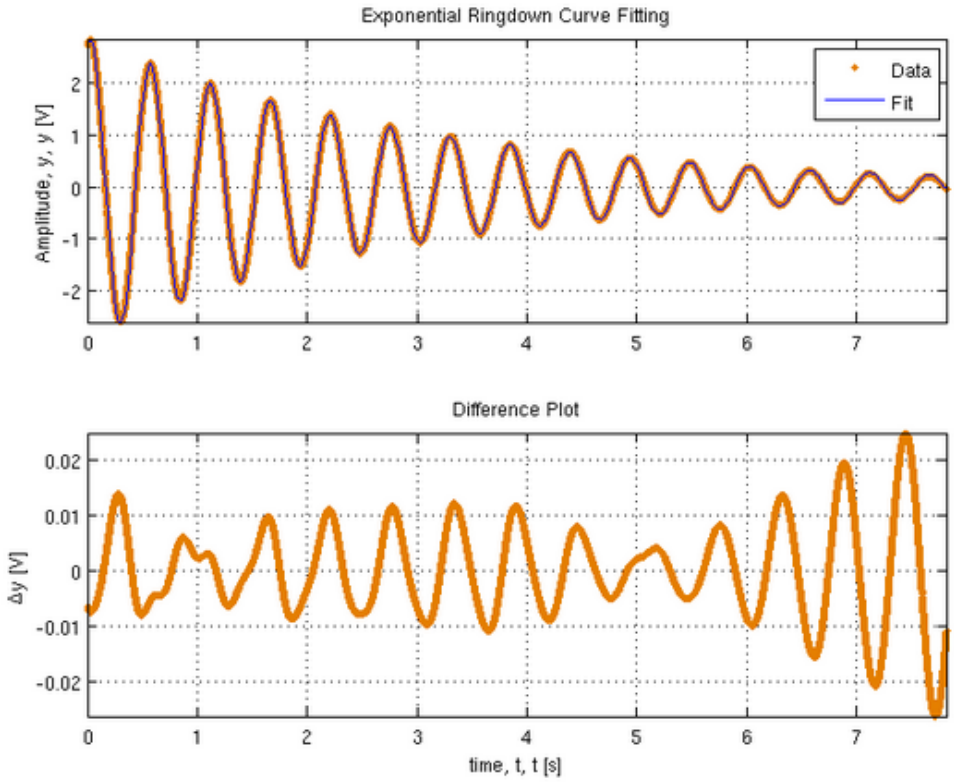
Fit of the Envelope Minima




```
No clear systematic in the difference plot
```
Fit of the Envelope Minima

```
Fitting Function:
 x(t)=x_0 exp(-x/tau)+x_1

Parameters:
     x_0 = ( -0.85795 +- 0.00253 )V
     tau = ( 3.20565 +- 0.00749 )s
     x_1 = ( 0.05665 +- 0.00222 )V

Degrees of Freedom, v = 10

Reduced ChiSquare X^2/v = 1

Standard Deviation Residuals STDR = 0.0011593 V

Correlation Matrix:
                      x_0  1.00
                      tau -0.98  1.00
                      x_1 -0.99  0.95  1.00

Comments:
Reduced chi square value set ad hoc, uncertainties are reliable only
if there are no systematic errors and noise is purely gaussian.
```

Fit of the RingDown



Clear systematic in the difference plot
Fit of the RingDown

Fitting Function:
 y(t)=Y exp(-t/tau) sin(w t+phi)+Y0

Parameters:
```
                      Y = -2.88155 V
                    tau = 3.03892 s
                      w = 11.5193 rad/2
                    phi = -1.89837 rad
                     Y0 = -0.000258485 V
```

Degrees of Freedom, v = 7812

Standard Deviation Residuals STDR = 0.00866848 V

Correlation Matrix:
```
                       Y  1.00
                     tau  0.72  1.00
                       w  0.03  0.03  1.00
                     phi -0.05 -0.03 -0.73  1.00
                      Y0  0.01  0.00 -0.03  0.05  1.00
```

Comments:
Reduced chi square value set ad hoc, uncertainties are reliable only
if there are no systematic errors and noise is purely gaussian.
Parameters' uncertainties not printed because data point uncertainties are not provided.

Final analysis

FTT   : Frequency mode f(1) = (1.8325 +- 0.0352)Hz
Zero Crossing: Frequency mode f(1) = (1.833 +- 0.186)Hz
Ring down fit: Frequency mode f(1) = (1.8333496 +- 0.0000126)Hz

#	tau [s]	stau [s]	Q [#]	sQ [#]
Maxima Env.	3.2009010e+00	6.0319717e-03	1.8427355e+01	1.1231570e-01
Minima Env.	3.2056539e+00	7.4859596e-03	1.8454716e+01	1.1317598e-01
Ringdown	3.0389186e+00	7.1745881e-04	1.7494833e+01	1.1072847e-01
Avg	3.0426546e+00	7.0923234e-04	1.8117937e+01	6.4697623e-02

Comments

Quality factor measurement seems reliable. Quality factor is on the low side and certainly below the nominal requirement (Q<100)
Number of magnet can be reduced probably down to a factor 2 by increasing the copper plate thicknessand maintaining a quite low quality factor

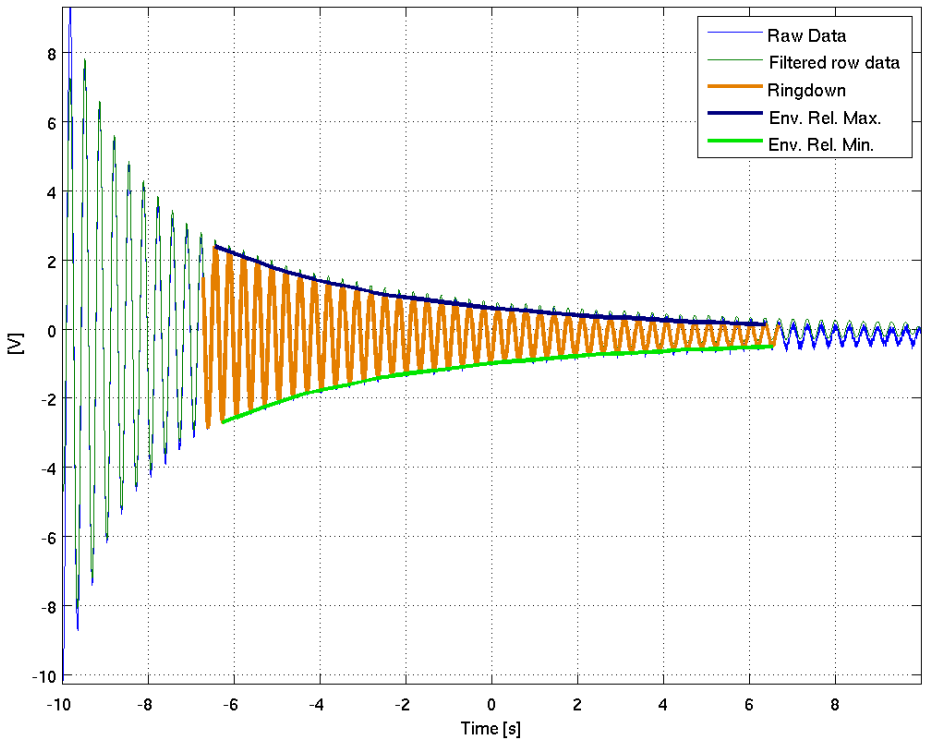
Date: Monday May 18th, 2011

CPB Suspension: Ringdown Roll Mode

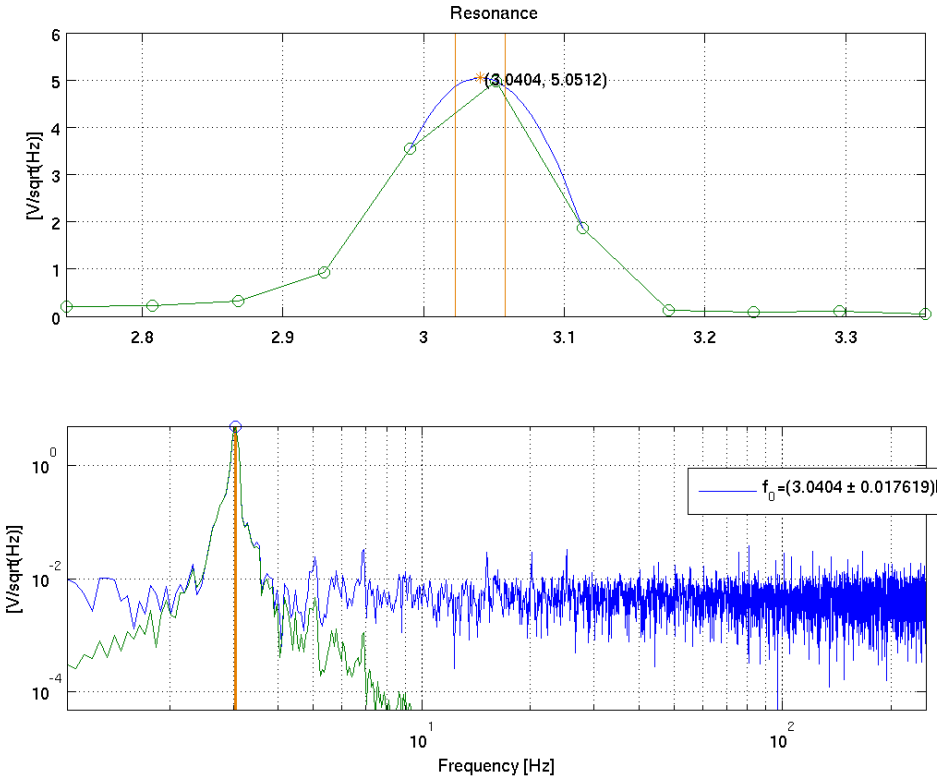
Cryogenic Pump Baffle (CPB) suspension ring-down measurement
Number of magnets: 4
Copper plates: 2
Direction: Y , horizontal parallel to laser beam axis

Exponential RingDown Analysis

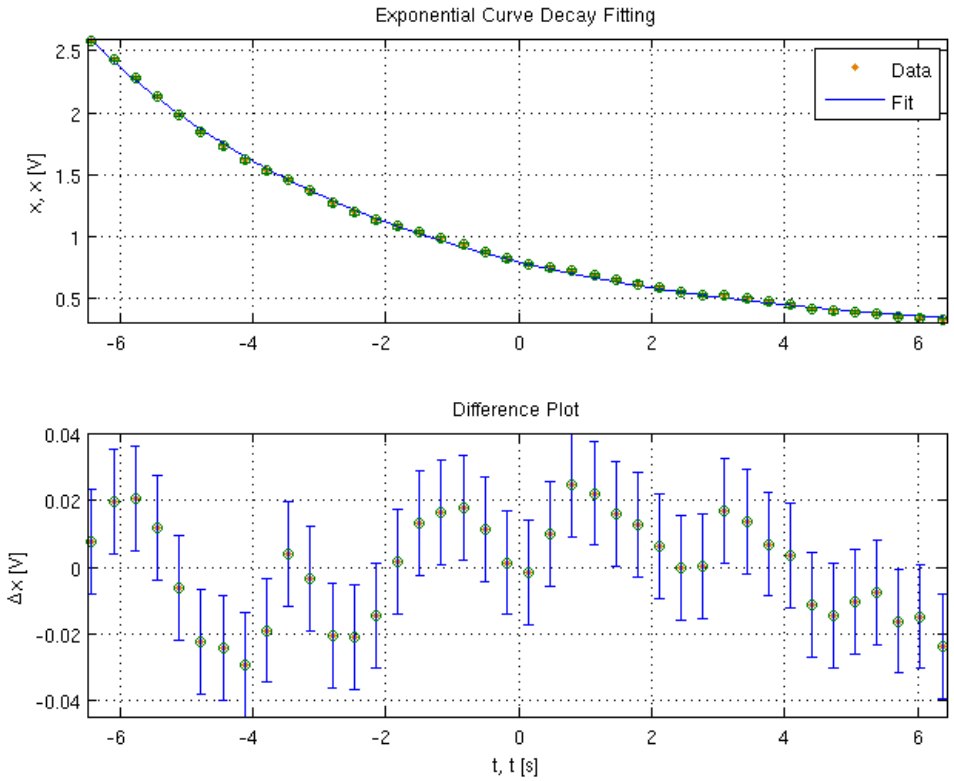
Raw Data and Envelopes Calculation



First and last 10 periods not used because of the systematic introduced by the aggressive filtering
Resonant Frequency Determination



Resonant frequency vertical mode.
Fit of the Envelope Maxima



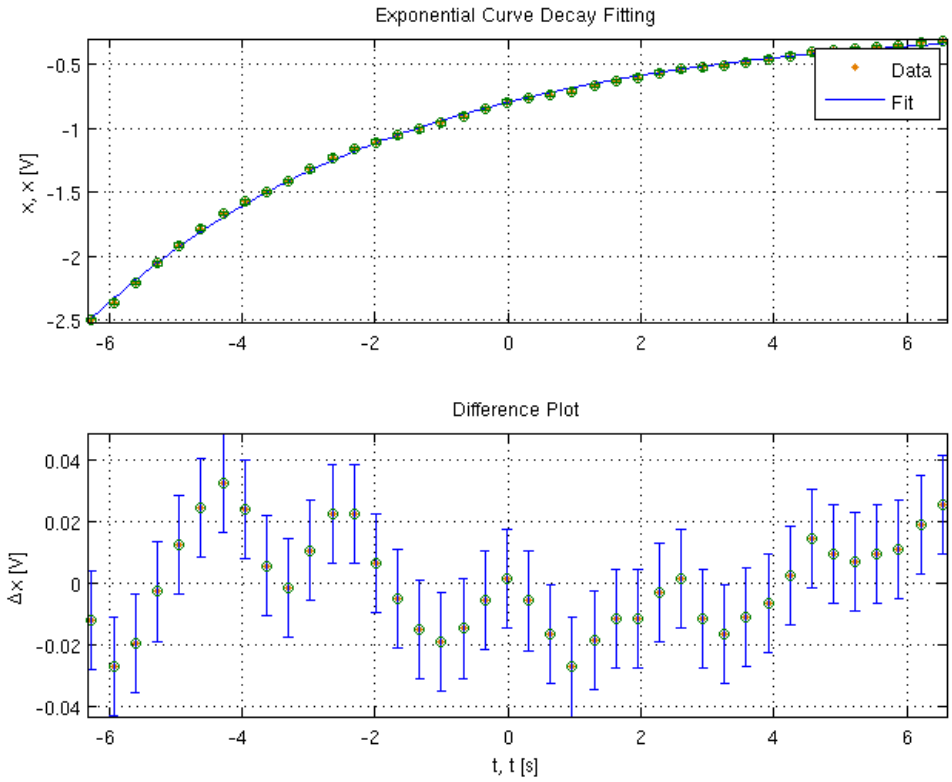
Clear systematic in the difference plot
Fit of the Envelope Maxima

Fitting Function:
 x(t)=x_0 exp(-x/tau)+x_1

Parameters:
     x_0 = (0.6009 +- 0.0117)V
     tau = (4.6680 +- 0.0598)s

```
     x_1 = ( 0.1922 +- 0.0103 )V

Degrees of Freedom, v = 37

Reduced ChiSquare X^2/v = 1

Standard Deviation Residuals STDR = 0.0152639 V

Correlation Matrix:
                      x_0  1.00
                      tau  0.98  1.00
                      x_1 -0.96 -0.92  1.00

Comments:
Reduced chi square value set ad hoc, uncertainties are reliable only
if there are no systematic errors and noise is purely gaussian.
```

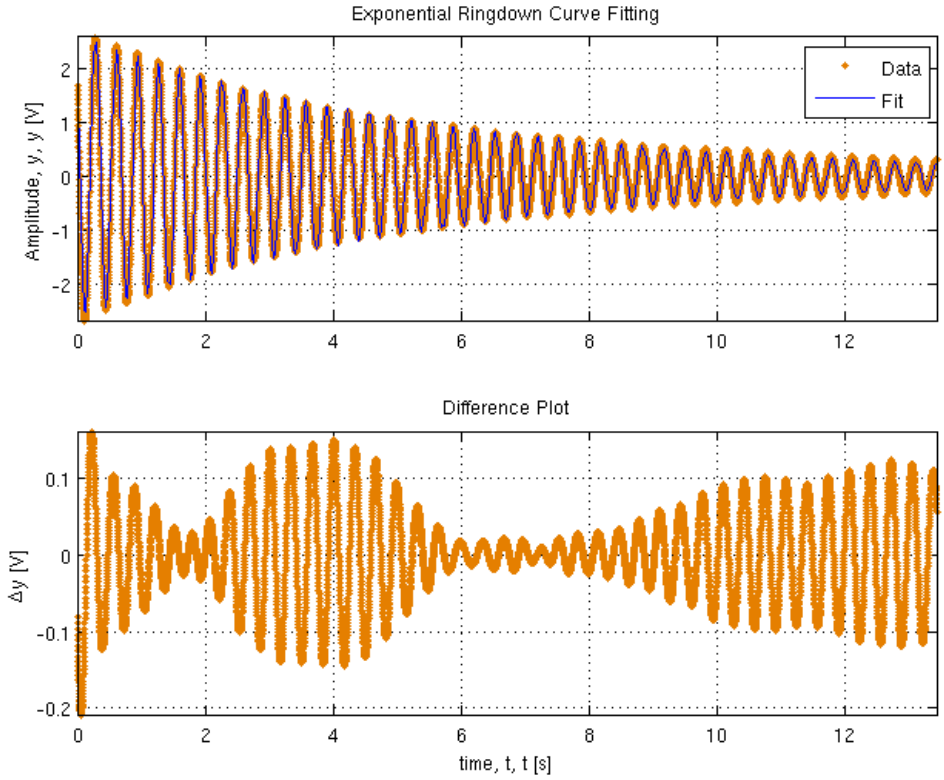
Fit of the Envelope Minima




```
Clear systematic in the difference plot
```
Fit of the Envelope Minima

```
Fitting Function:
 x(t)=x_0 exp(-x/tau)+x_1

Parameters:
     x_0 = ( -0.6071 +- 0.0122 )V
     tau = ( 4.7008 +- 0.0641 )s
     x_1 = ( -0.1867 +- 0.0106 )V

Degrees of Freedom, v = 37

Reduced ChiSquare X^2/v = 0.999999

Standard Deviation Residuals STDR = 0.0156197 V

Correlation Matrix:
                      x_0  1.00
                      tau -0.98  1.00
                      x_1 -0.96  0.92  1.00

Comments:
Reduced chi square value set ad hoc, uncertainties are reliable only
if there are no systematic errors and noise is purely gaussian.
```

Fit of the RingDown



Clear systematic in the difference plot
Fit of the RingDown

Fitting Function:
 y(t)=Y exp(-t/tau) sin(w t+phi)+Y0

Parameters:
```
                      Y = -2.63507 V
                    tau = 5.68867 s
                      w = 19.1182 rad/2
                    phi = -0.731578 rad
                     Y0 = -0.00051146 V
```

Degrees of Freedom, v = 6706

Standard Deviation Residuals STDR = 0.0653468 V

Correlation Matrix:
```
                       Y  1.00
                     tau  0.73  1.00
                       w -0.00 -0.00  1.00
                     phi  0.00  0.00 -0.73  1.00
                      Y0 -0.01 -0.01 -0.01  0.01  1.00
```

Comments:
Reduced chi square value set ad hoc, uncertainties are reliable only
if there are no systematic errors and noise is purely gaussian.
Parameters' uncertainties not printed because data point uncertainties are not provided.

Final analysis

FTT   : Frequency mode f(1) = (3.0404 +- 0.0176)Hz
Zero Crossing: Frequency mode f(1) = (3.046 +- 0.106)Hz
Ring down fit: Frequency mode f(1) = (3.0427533 +- 0.0000585)Hz

#	tau [s]	stau [s]	Q [#]	sQ [#]
Maxima Env.	4.6679819e+00	5.9803122e-02	4.4587309e+01	1.9586146e-01
Minima Env.	4.7008096e+00	6.4138595e-02	4.4900871e+01	2.0896197e-01
Ringdown	5.6886689e+00	1.1970139e-02	5.4336637e+01	6.6918511e-02
Avg	5.6186154e+00	1.1545595e-02	5.2609599e+01	6.0602847e-02

Comments

Quality factor measurement seems reliable. Quality factor is on the low side and certainly below the nominal requirement (Q<100)
Number of magnet can be reduced probably down to a factor 2 by increasing the copper plate thicknessand maintaining a quite low quality factor