

The CML Slider-Air Bearing Parameter Identification Program

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Abstract

This report presents a detailed description of the slider-air bearing parameter identification program developed at the Computer Mechanics Laboratory at the University of California at Berkeley. The program uses the impulse responses of sliders to obtain modal parameters -modal frequencies, damping ratios and mode shapes- of slider-air bearings. The physical matrices (mass, stiffness and damping) of the slider air bearings are calculated from the modal parameters. The “true” mass matrix is used to update the estimated physical matrices. Although the current version is primarily designed for processing dynamic simulation data, the program can also be applied to analyze experimental data. The program is written in MATLAB, and it can be run with Unix, Windows and DOS environments. The program provides many features for visualizing the data - displaying impulse response curves, frequency response function curves, curve fits, animating the mode shapes, and showing nodal lines of the shapes.

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1. Introduction

As flying heights continue to decrease, the intermittent contact and impact of the slider and disk's asperities in the normal operation state are unavoidable. It is then essential for the slider's fluctuation induced by the impacts to be rapidly damped out so that the successive impacts will not drive the slider motion into resonance and result in a crash. Recent research [1] also shows that flying height fluctuation can thermally induce the MR signal disturbance even while no actual head/disk contact occurs in the process, and therefore controlling the fluctuation is important for sliders with the MR elements. The fluctuation is directly related with the dynamics properties of slider-air bearings. Therefore, the evaluation of the dynamic properties, such as stiffness and damping, of the air-bearings becomes an important concern.

Recently, we [2,3] proposed using the modal analysis method to analyze the dynamic properties of slider-air bearings. Using this method, the properties can be easily obtained from simulation or experimental data. The simulation results show that the method is a versatile tool for head-medium interface analysis. The method has been implemented by the CML Slider-Air Bearing Parameter Identification Program that is described in this report. The program is written in MATLAB, and it can be run in Unix, Windows and DOS environments. Although the current version is mainly designed for processing dynamic simulation data, the program can also be applied to analyze experimental data. The program uses the impulse response of sliders to obtain modal parameters -modal frequencies, damping ratios and mode shapes- of slider-air bearings. The physical matrices (mass, stiffness and damping) of the slider air bearings are calculated from the modal parameters. The program provides many features for visualizing the data - displaying impulse responses, impulse response function (IRF) curves, frequency response function (FRF) curves, and curve fits; animating the mode shapes; and showing nodal lines of the shapes. The theoretical background and procedure have been described

in the previous reports [2,3], so, this report will only describe how to use the program. It is necessary for the user to have some knowledge of and experience with slider air bearing design [4] and dynamic simulation [5], mechanical vibration and structural dynamics, and signal analysis and parameter identification.

2. Installation and File Organization

2.1 Installation and Compiling

All files are packed in one ZIP file. Create a directory (i.e., **cmlpip**) to hold all of the files, download ZIP files **cmlpip.zip** (for the PC) or **cmlpip.tar.Z** (for the Workstation), and save them into the **cmlpip** directory. For the PC (Windows 95), use the WinZip program to unzip it into the directory (the *User Folder Names* item in the extract dialogue box of the WinZip program should be active). For the Workstation (Unix), use commands

```
uncompress cmlpip.tar
```

and

```
tar -xvf cmlpip.tar
```

to obtain all files. All MATLAB program M-files and FORTRAN source code files are placed in the **cmlpip** directory, and the data files of the two examples are organized into two sub-directories: **tf** (taper flat slider) and **nut** ("Nutcracker" slider). If the user wants to use the CML dynamic simulator to create the impulse responses for the program, he needs to compile the FORTRAN source code files. The files are modified from the simulator so the users can conveniently obtain the required data. For DEC alpha machines, please use the following command (or similar command) line to compile the **d366pip.f** file:

```
f77 -o d366pip d366pip.f
```

For IBM machines, use the following command (or similar command) line to compile the **d366pipr.f** file:

```
f77 -o d366pip d366pipr.f
```

After compiling is finished, the executable file name is **d366pip**, and it is stored in the **cmlpip** directory.

2.2 File Organization

In the two examples, each calculation case has a different sub-directory. The job name (or case name) is used as the sub-directory name. It is recommended that the job name be less than eight characters and consist of characters a-z and 0-9 (lower case is suggested for comparability of files between UNIX and DOS systems). As an example, in the **nut** sub-directory, there are the following data files.

Source input files

- dyndef.zpr** Data header file for saving calculation parameters for the impulse responses.
- impresp.z** Impulse responses for the excitation in the Z (vertical) direction.
- impresp.p** Impulse responses for the excitation in the P (pitch) direction.
- impresp.r** impulse responses for the excitation in the R (roll) direction.

Data files for calculation

- nut.mat** MATLAB data file including all of the data in this job.
- irf.z , irf.p, irf.r** IRFs for the excitation in the Z, P and R directions.
- frf.z, frf.p, frf.r** FRFs for the excitation in the Z,P and R directions.
- fit.z, fit.p, fit.r** Curve fits of FRFs for the excitation in the Z, P and R directions.
- frfhd.dat, freqlin.dat** Calculation parameter files.

Results file

- modpara.dat** Results file in which all results (modal parameters and physical matrices) are included.

Additional files (optional)

runzpr	Batch file for UNIX systems running the CML Dynamic Simulator to obtain the impulse responses for the excitations in Z, P and R directions.
fh0.dat	Steady flying attitudes generated by runzpr
dyndef.0	Input file for the simulator calculating the steady flying attitudes of the sliders.
dyndef.z, dyndef.p, dyndef.p	Input files for the simulator calculating the impulse response for the excitations in the Z, P and R directions.
rail.dat	Rail data of the slider.
rshape.dat	3-D shapes data of the slider for displaying the 3-D rail shape.
x.dat, y.dat	x and y coordinates
p2.dat	Pressure profile.

3. Procedure and Interface Guide

Figure 1 shows the procedure that is recommended for using the program. The program can process two kinds of source data: CML Dynamic Simulator's input files (**dyndef.0**, **dyndef.***) and source input files (**dyndef.zpr**, **impresp.***). After the job name is created and a corresponding sub-directory is made by the program, the source data files should be prepared in the sub-directory.

3.1 Preparing Source Data

3.1.1 Source data calculated by the CML dynamic simulator.

The **rail.dat** file should be available for using the simulator. The user should edit the four input files (**dyndef.0**, **dyndef.***), and pay attention to the following items in the files. ❶ Time step dt is usually equal or less than 1×10^{-7} second, and the step will significantly effect the estimated damping as shown in Figure 2 of the previous report [3]. Total time duration tf is usually between .0002 second and .0004 second. The dt and tf in files **dyndef.z**, **dyndef.p** and **dyndef.r** should be the same. ❷ Initial flying attitudes hm , hp

and *hr* in the **dyndef.0** file should be carefully selected. The results of some sliders, such as the “Nutcracker”, Headway AAB sliders (sliders with negative pressures), are very sensitive to the initial flying attitudes. ❸ It is recommended that the initial speeds *vz*, *vp* and *vr* be selected as: *vz=vp=vr=0* for **dyndef.0**; *vz=.002* and *vp=vr=0* for **dyndef.z**; *vp=.004/xl* (*xl* is slider’s length, m), *vz=vr=0* for **dyndef.p**; and *vr=.004/xl*, *vz=vp=0* for **dyndef.r**. ❹ The grid control is set to *iadpt=1* and *ioldgrid=0* for **dyndef.0**, and *iadpt=0* and *ioldgrid=1* for **dyndef.z**, **dyndef.p** and **dyndef.r**. ❺ The **dyndef.*** files should be identical with the **dyndef.0** file except the initial flying condition, the grid control, *dt* and *tf*. If the **dyndef.*** and **rail.dat** files are available in the current job’s sub-directory, type the command **runzpr** to execute the simulator in this sub-directory. It will spend one or two hours for simple taper flat designs, or one or two days for some negative pressure designs to finish the calculation. (To reduce the time, use a larger time step to find the initial flying attitudes, and then only calculate the impulse responses for the excitations in the roll and vertical (or pitch) directions. If only modal frequencies and damping ratios are of interest, the user can calculate only the impulse responses for a combined excitation (i.e., *vz=.002*, *vp=0*, *vr=.2*) called the excitation in the Z direction). After the calculation is finished, the program can be continued to find the required results.

3.1.2 Source input files.

If the source data is not calculated by the simulator, the data can be input from the source input files **dyndef.zpr** and **impresp.***. The formats of the files are as follows.

Sample **dyndef.zpr**

<i>/net/cml/cmlvol2.....</i>	Line 1: Comment line
<i>5400rpm 25mm 0Deg 0mAlt 3.5gram</i>	Line 2: For references
<i>Dimensions (Length, width, height, m)</i>	Line 3: Comment line
<i>0.002 0.0016 0.00042</i>	Line 4: Dimensions of the slider (m)
<i>Mass(kg) Ip(kg*m^2) Ir(kg*m^2)</i>	Line 5: Comment line
<i>5.95189E-06 2.17611E-12 1.36144E-12</i>	Line 6: Inertia parameters
<i>Relative speed (m/s), skew angle (degree), N/A</i>	Line 7: Comment line

14.1372 0 0	Line 8: For reference
Coordinate(X,Y,Z) of the points which response calculated	Line 9: Comment line
.002 .0008 0	Line 10: Coordinates (m), the point is located at the trailing edge's center on the ABS of the slider
dt(s), Number of points, Excitation type(1 impulse 2 Bump)	Line 11: Comment line
1E-07 2001 1	Line 12: Time step and number (<i>N</i>) of lines in the impresp.* files
Initial speed (m/s, rad/s) for impresp.z	Line 13: Comment line
0.002 0 0	Line 14: Initial speed (m/s) for creating the impresp.z files.
Initial speed (m/s, rad/s) for impresp.p	Line 15: Comment line
0 2 0	Line 16: Initial speed (m/s) in for creating the impresp.p files.
Initial speed (m/s, rad/s) for impresp.r	Line 17: Comment line
0 0 2	Line18: Initial speed (m/s) in for creating the impresp.r files.

Sample of **impresp.z**, **impresp.p** and **impresp.r** files

4.80600E-08	5.79953E-05	3.05880E-06	Line 1
4.82598E-08	5.79954E-05	3.05881E-06	Line 2
⋮	⋮	⋮	
4.90650E-08	5.71222E-05	3.10094E-06	Line <i>N-1</i>
4.90755E-08	5.71233E-05	3.10164E-06	Line <i>N</i> (<i>N</i> is specified in dyndef.zpr)
Vertical	Pitch	Roll	
(m)	(rad)	(rad)	

3.2 Interface Guide

Run MATLAB to enter the MATLAB environment, and change the current directory into **cmlpip**. Enter **pip**, the data saved in file **matlab.mat** (the file is created when you exit

the program) in directory **cmllpip** will be automatically loaded, and a window will appear at the left-top corner of the screen. This is the main window of the program. When the program is run, there are at least three windows: main window (Window 1), MATLAB output window (Window 0) and program output window (Window 2). All official output of the program will be shown in the program output windows. The main window as shown in Figure 2 includes three parts: Menu Bar, Current Status, and Messages.

3.2.1 Current Status

The Current Status includes four lines:

Current job: showing the current job name.

FRF data: indicates availability of FRFs (excitation in Z, P or R).

Results: indicates number of modes obtained.

Current window: shows current program output window number (≥ 2).

3.2.2 Menu bar

The menu bar has six parts: *File*, *GetData*, *Estimate*, *DisplayCurves*, *Results*, *Windows and Print*.

File menu. There are five selections under the *File* menu: *Open or create a job*, *Save current job*, *Save current results table as*, *Load results table* and *Exit*.

- 1) If *Open or create a job* is selected, a dialogue box appears, the user can enter a job name, and click the *OK* button. If the job name exists, the data saved in file **jobname.mat** (such as **nut.mat**, **tf.mat**) in the sub-directory will be loaded, The Current Status of the job will be shown in the main window. If this is a new job, a sub-directory will be created with the job name.
- 2) If *Save current job* is selected, the data in memory will be saved into the **jobname.mat** file in the current job directory.
- 3) If *Save current results table as* is selected, a dialogue box appears, then the user can enter a name (no character dot in the name). After clicking the *OK* button, the data

shown in the results table will be saved as a MATLAB data file (**.mat**) in a sub-directory of the current job.

- 4) If Load results table is selected, a dialogue box appears, then the user can enter the name (**.mat**) and click the OK button to load the data in the file created by Save current results table as.
- 5) If Exit is selected, the program will be finished and exits the MATLAB environment. The current data in memory will be automatically saved into the **matlab.mat** file in the **cmlpip** directory.

GetData menu. There are five selections under the *GetData* menu: Show 2-D rail, Show 3-D rail, Show pressure profile, Get data from the simulator, and Calculate IRFs and FRFs.

- 1) Select Show 2-D rail to display the 2-D rail shape. The **rshape.dat** file will be needed and the rail 2-D shape will be shown in the current window.
- 2) Select Show 3-D rail to display the 3-D rail shape. Files **rshape.dat**, **x.dat** and **y.dat** will be read and the 3-D rail shape will be shown.
- 3) Select Show pressure profile to display the 3-D pressure profile. Files **p2.dat**, **x.dat** and **y.dat** will be used and the 3-D pressure profile will be shown.
- 4) If Get data from the simulator is selected, a dialogue box appears, then the user can enter two path names. The first (From:) is the source in which there are files **dyndef.z**, **dyndef.p**, **dyndef.r**, **fhhist.z**, **fhhist.p** and **fhhist.r** (i.e., From: /cmlvol2/userx/cmlpip/nut). The second (To:) is the target in which files **dyndef.zpr**, **impresp.z**, **impresp.p** and **impresp.r** will be generated and saved (i.e., To: /cmlvol2/userz/cmlpip/nut). Then, Calculate IRFs and FRFs is automatically executed.
- 5) If Calculate IRFs and FRFs is selected, a dialogue box appears, the user can specify the frequency band of interest. The band from 0 to 190 or 290 kHz is recommended. After the OK button is clicked, the program will read files **dyndef.zpr**, **impresp.z**, **impresp.p** and **impresp.r**, and calculate the IRFs (**irf.z**, **irf.p** and **irf.r**) and FRFs

(**frf.z, frf.p and frf.r**). Then, the Current Status (FRF data) in the main windows will show in which direction (Z, P and R) the FRFs are available under the excitation. At least one (Z, P or R) is required.

Estimate menu. There are two selections under the *Estimate* menu: Automatic estimate and Interactive estimate. Ordinarily, good results should be obtained by the Automatic estimate. For experienced users, better results can be found by using the Interactive estimate. The **fit.*** and **parares.dat** files will be created after the estimation.

- 1) If Automatic estimate is selected, the program will automatically perform the parameter estimation. The program reads and processes the FRF files to obtain FRF curve fits, modal parameters, initial physical matrices (mass, stiffness and damping matrices of the slider-air bearings) and the matrices that are updated by the “true” inertia parameters given in files **dyndef.***.
- 2) If Interactive estimate is selected, a dialogue box, shown in Figure 3, appears. ❶ The user can specify the FRFs that are used to estimate the modal parameters. It is recommended that all three FRFs or two FRFs be selected (one is Roll, another is Vertical or Pitch). In many cases, good results can be obtained by selecting two FRFs. ❷ The user can set the frequency band by entering numbers in the *From* and *To* boxes. The best way is by using the Set by mouse button to specify the band. After clicking the button, the averaged FRF curve, which is similar to one shown in Figure 4, will be displayed. By moving the mouse point to the lower frequency point on the curve and clicking the left key of the mouse, and then moving the point to the higher frequency point on the curve and clicking the left key of the mouse, the frequency band is specified and automatically shown as in Figure 5. The lower and upper frequencies of the band will also be shown in the *From* and *To* boxes. By clicking the Show the band button, you can check the frequency band to be used for the curve fitting. ❸ The user needs to specify the mode number to save the modal parameters. There are only three modes. The user can specify the frequency band in which three peaks of the FRFs are included, and give *Mode no. start* 1 and *Estimat* 3 (Figure 3) to

obtain all modes. The modes can also be separately estimated. If the second and third peaks in the FRFs are close to each other, it is recommended that the first mode be separately estimated (the frequency band only includes the first peak, set *Mode no. start* and *Estimat* to 1), and then the second and third modes are estimated together (the frequency band only includes the second and third peaks; specify *Mode no. start* and *Estimat* as 2). ④ After all parameters are specified, click the Do estimate button to perform the curve fitting to obtain the modal parameters. Click the Exit estimation button to exit the interactive estimate menu.

DisplayCurve menu. There are nine selections under the *DisplayCurve* menu. They can be used to display the curves of the flying attitude for the impulse excitations, IRFs, FRFs and curve fits.

- 1) The Flying attitude for vertical excitation, Flying attitude for pitch excitation and Flying attitude for roll excitation menus were designed for displaying the impulse responses of the sliders in the vertical (at the point specified in the **dyndef.zpr** file), pitch and roll directions for the different excitations. As an example, Figure 6 shows the impulse responses of the taper flat slider for the excitation in the roll direction. The **dyndef.zpr** and **impresp.*** files are used.
- 2) The IRFs and FRFs for vertical excitation, IRFs and FRFs for pitch excitation and IRFs and FRFs for roll excitation menus can be used to display the IRFs and FRFs of the sliders for the different excitations. Figure 7 shows the IRFs and FRFs for the excitation in the pitch direction. The **irf.*** and **frf.*** files are used.
- 3) The IRFs, FRFs and curve fits for vertical excitation, IRFs, FRFs and curve fits for pitch excitation and IRFs, FRFs and curve fits for roll excitation menus can be used to display the IRFs, FRFs and curve fits. Figure 8 shows the IRFs, FRFs and curve fits for the excitation in the vertical direction. The **irf.***, **frf.*** and **fit.*** files are used. After the estimation of the parameters is performed, one should check the FRFs and curve fits to find whether the curve fits are close to the FRFs. If they are close to each other in the bands in which FRFs have a large amplitude, that means the curve fitting

or estimation is good. Otherwise, we need to change the parameters of estimation, such as the frequency band, and perform the estimation again.

Results menu. There are six selections under the *Results* menu, which can be used to display the final results, such as the modal parameters, physical matrices, the nodal lines of the mode shapes, and animation of the mode shapes.

1) If *Result table* is selected, all results will be shown in the current window, shown as Figure 9. The results table includes the following data. The *flying height* shows the steady flying height of the slider at the specified point. The modal frequencies and damping ratios have kHz and percentage (% to critical damping) units, respectively. The mode shapes are complex, and shown as *Amp* (amplitude, the first component has a unit of $\text{kg}^{-1/2}$, and the second and third have units of $\text{m}^{-1}\cdot\text{kg}^{-1/2}$ and *Phase* (degree). Ordinarily, if the phases of the three mode shapes are close to 0 or 180 (or -180), the slider-air bearing system can be considered as a system with proportional damping. The *Physical Matrices* (*Mass*, *Stiff* and *Damp*) are the estimated mass, stiffness and damping matrices that are directly calculated from the modal parameters. Their units are defined by kg, m, s. The *Updated Matrices* are calculated by using the inertia parameters of the slider. If the suspension is modeled by three springs and dampers, the updated mass matrix should be the true mass matrix of the system. Then, the differences between the estimated and updated mass matrices can be used to indicate the errors of the modal parameters. If the differences of the diagonal elements is very small (e.g., less than 10%), that means that we can use the program to evaluate the system, and there should be no mistakes in the whole calculation procedure (from the dynamic simulation to the curve fitting). Ordinarily, the small differences can be achieved by properly using *Interactive Estimate*. Larger differences often result from three sources. The first source is from errors in the **dyndef.zpr** file. The second is improper initial flying conditions used in the dynamic simulations. The third is the non-linear properties of contact recording sliders, such as the Tripad slider. Although

the modal parameters are not very accurate for the contact recording sliders, the results may still be very helpful for the slider design.

- 2) If *Nodal lines with a full table* is selected, the nodal lines of the mode shapes and a table will be shown as Figure 10. The numbers nearby the lines represent the mode number. The *Slope(deg)* in the table are the slopes of the nodal lines with respect to the horizontal (X) axis, and the *Intercept(mm)* are the interceptions between the nodal line with the vertical (Y) axis.
- 3) If *Nodal lines with a small table* is selected, the nodal lines of the mode shapes, slopes and interceptions will be displayed in the current window as Figure 11.
- 4) If *Mode 1 Animation* is clicked, the animation of the shape of mode 1 will be displayed in the current window as Figure 12.
- 5) Click *Mode 2 Animation* to display the animation of mode 2.
- 6) Click *Mode 3 Animation* to display the animation of mode 3.

Windows menu. By selecting the *Windows* menu, and clicking *Specify current window*, the user will see a dialogue. Enter a number that is larger than one (≥ 2), and click the *OK* button to specify the current window. All output of the program will be sent to the current window while the user is operating the program. Changing the current window is often used in comparisons of the data.

Print menu. By clicking the *Print* menu, the user will see a dialogue. Enter a file name without the extension name, and click the *OK* button to print the current window to the file in EPS format.

4. Summary

The CML Slider-Air Bearing Parameter Identification Program is described in this report. The files and interface of the program are fully presented. Using the program is not so difficult, but explaining and applying the results is not very easy. The modal analysis

method has been widely applied in structural dynamics and mechanical vibration. The method and the program should have much application potential in head-medium interface analysis and experiment.

Acknowledgments

This project is supported by the Computer Mechanics Laboratory at the University of California at Berkeley.

References

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- [3] Zeng, Q.H. and Bogy, D.B., 1997, “Stiffness and Damping Evaluation of Air Bearing Sliders by Modal Analysis Methods: New Designs with High damping”, CML Technical Report No. 97-002.
- [4] Lu, S. and Bogy, D.B., 1995, “The CML Air Bearing Design Program User’s Manual”, CML Technical Report No. 97-003.
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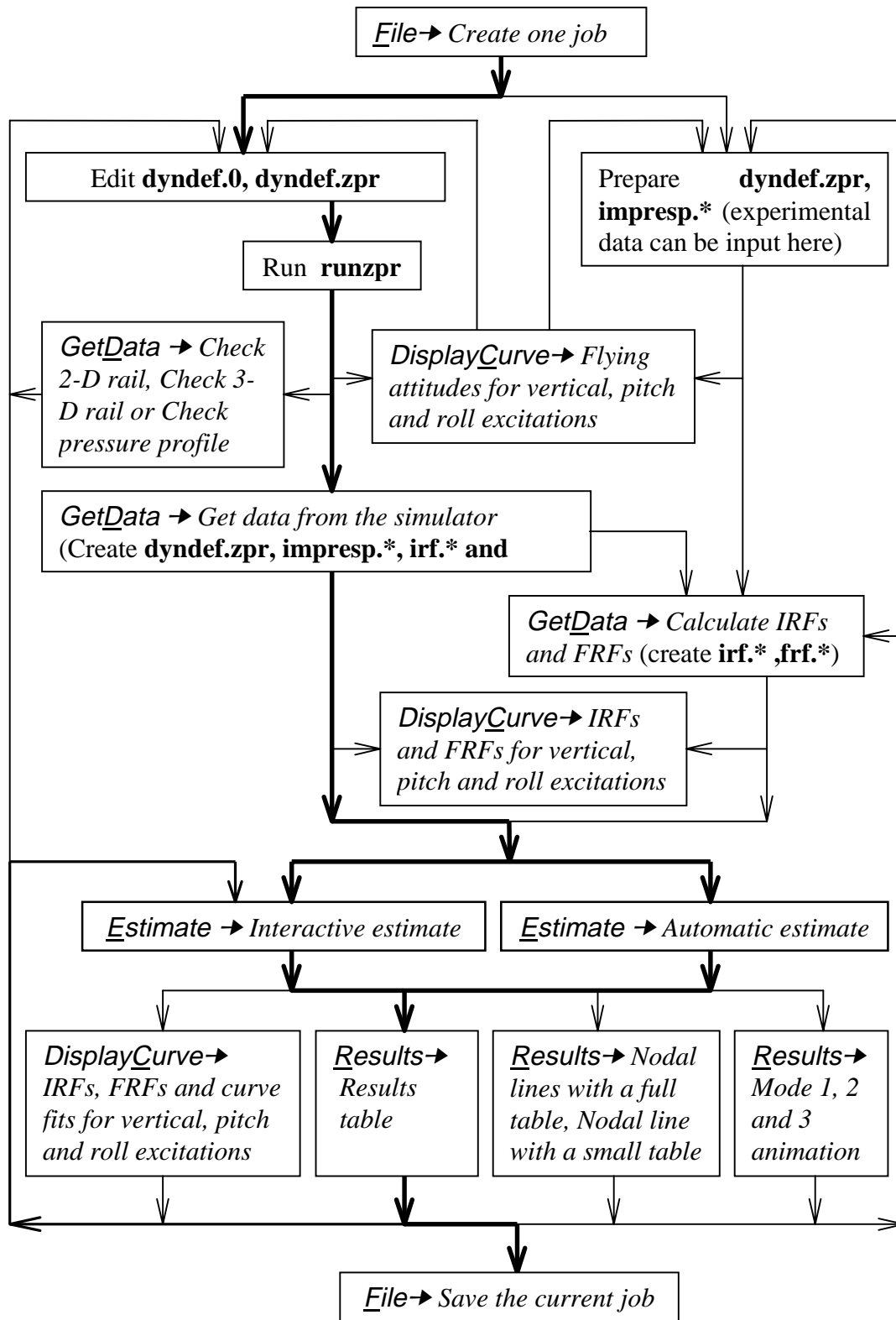


Figure 1 A procedure to identify the parameters of slider-air bearings

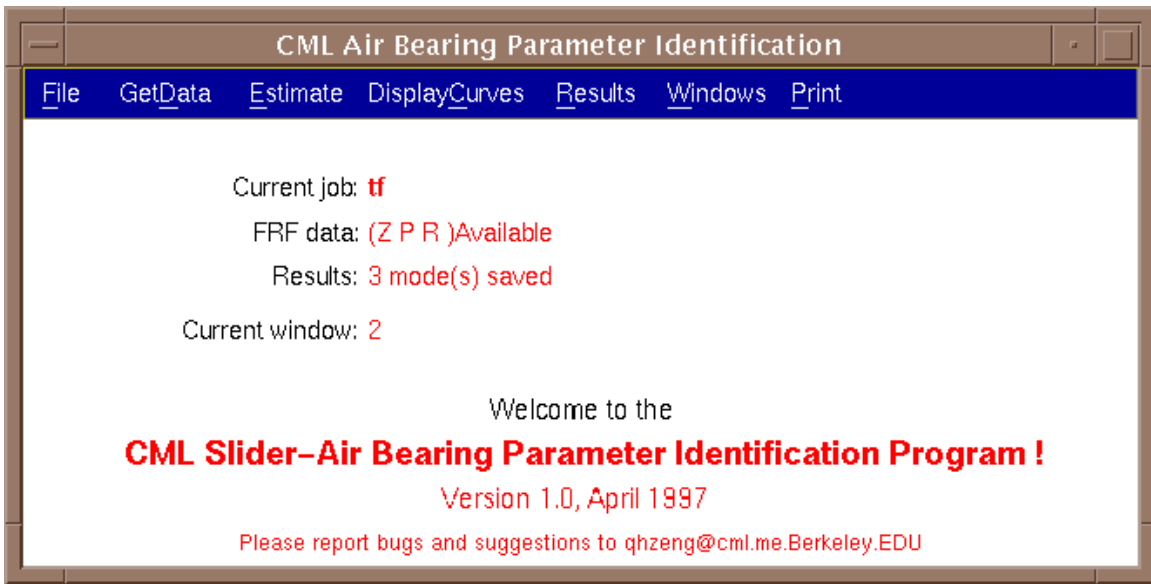


Figure 2 Main window of the program

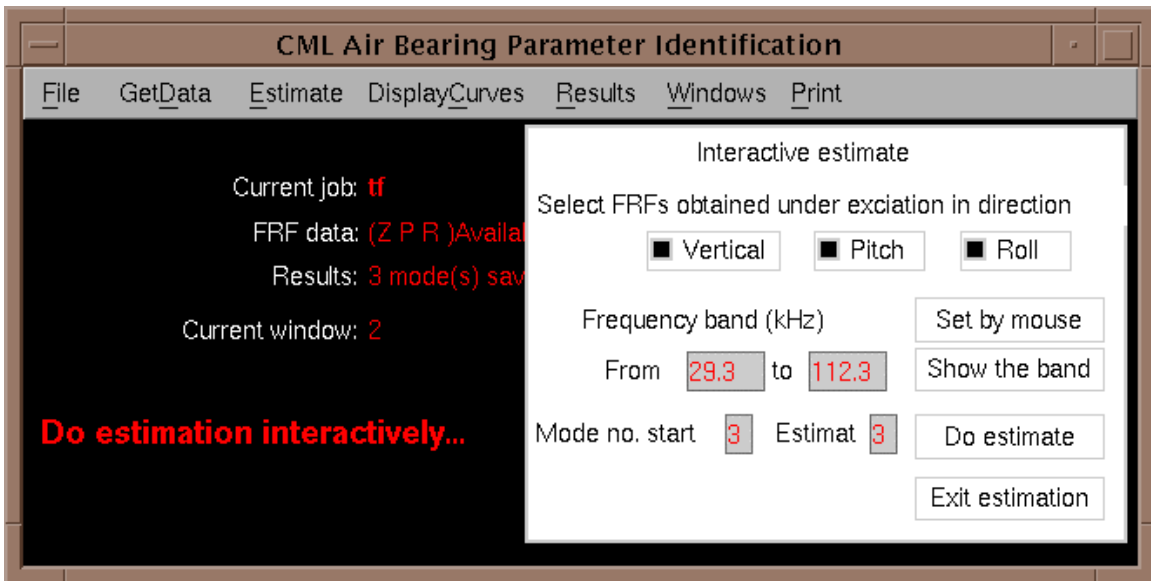


Figure 3 The dialogue box for interactive estimate

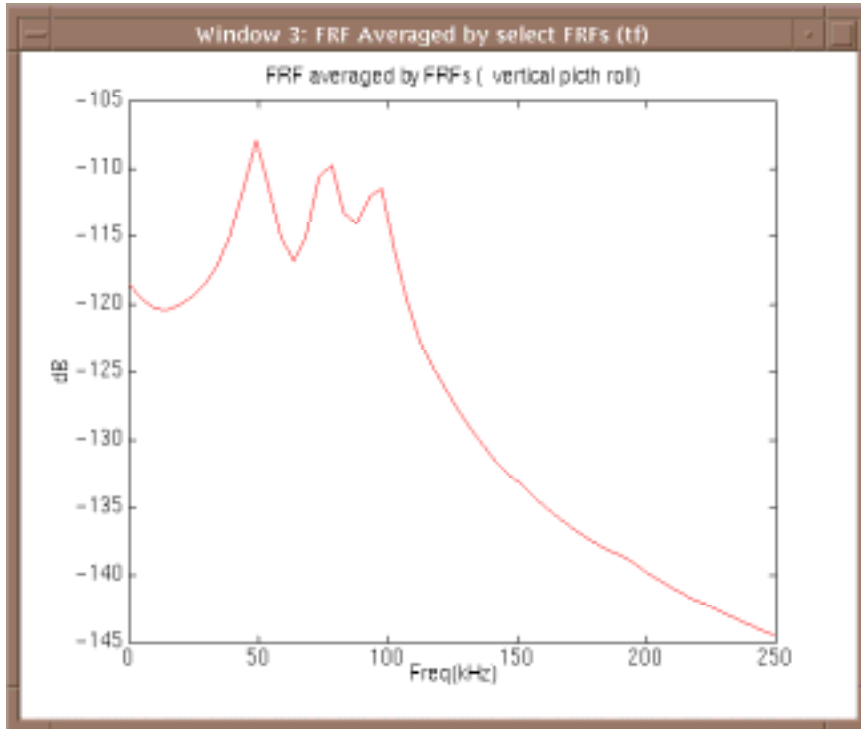


Figure 4 Averaged FRF curve for setting frequency band

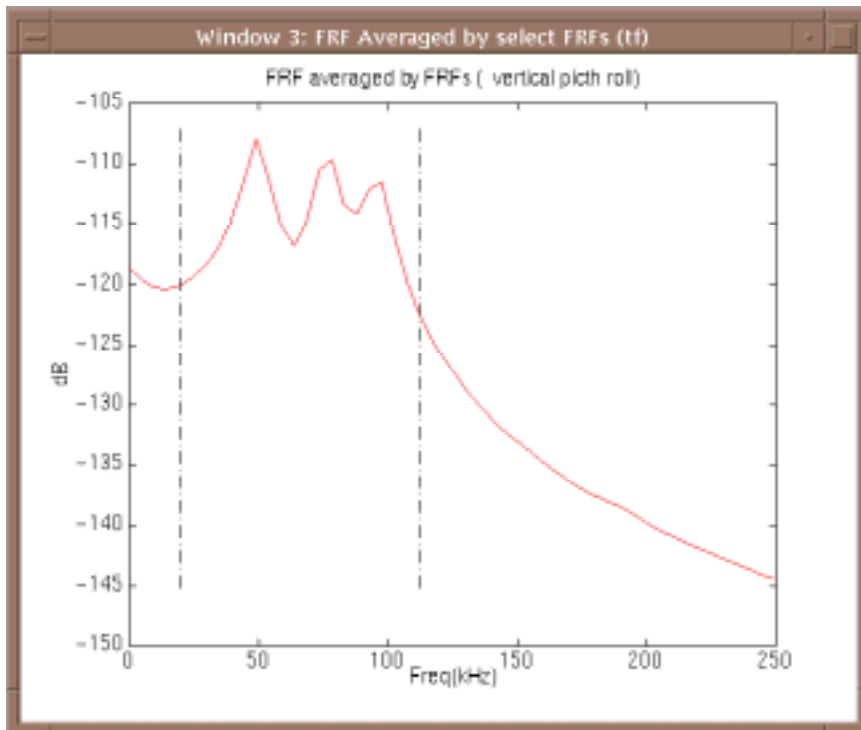


Figure 5 Averaged FRF curve after setting frequency band

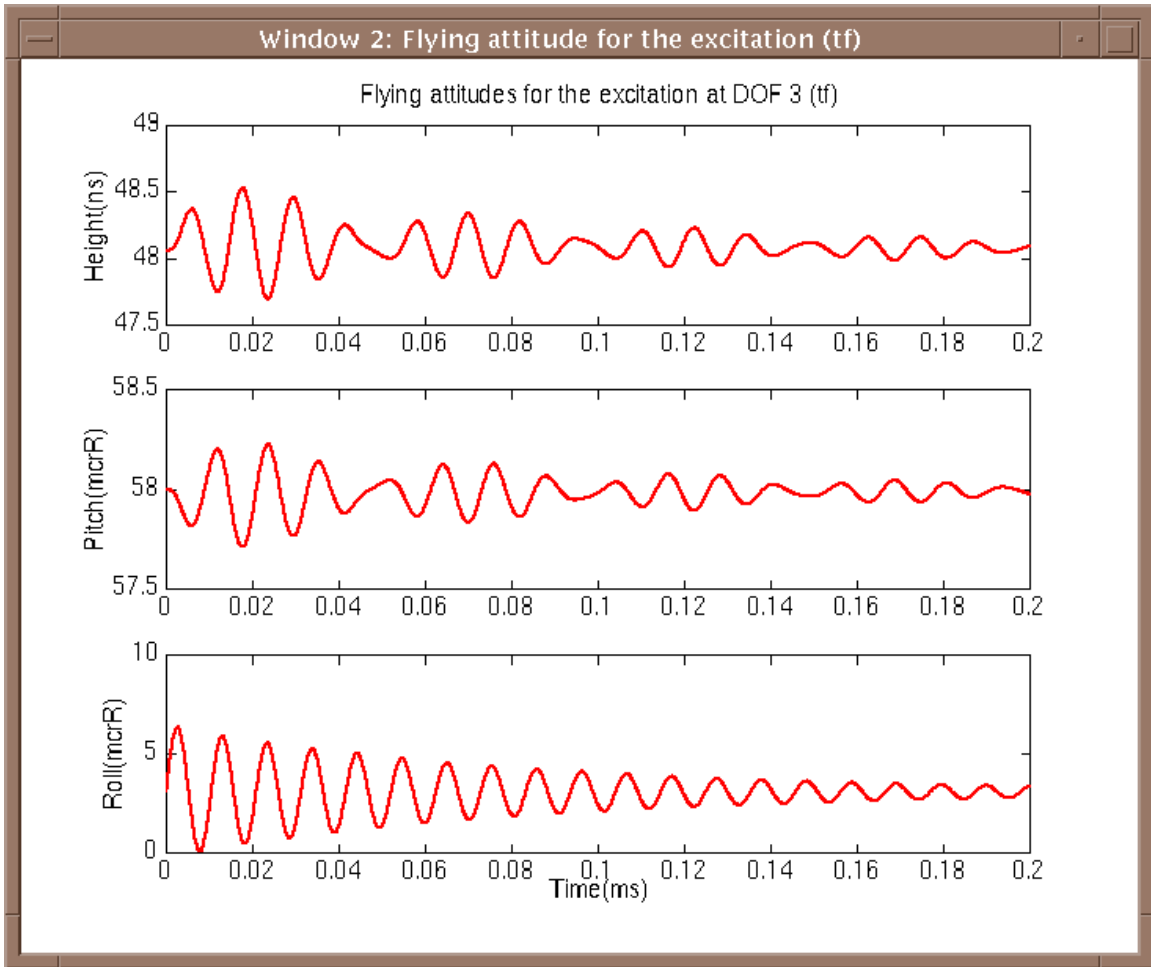


Figure 6 Flying attitudes for the excitation in the roll direction

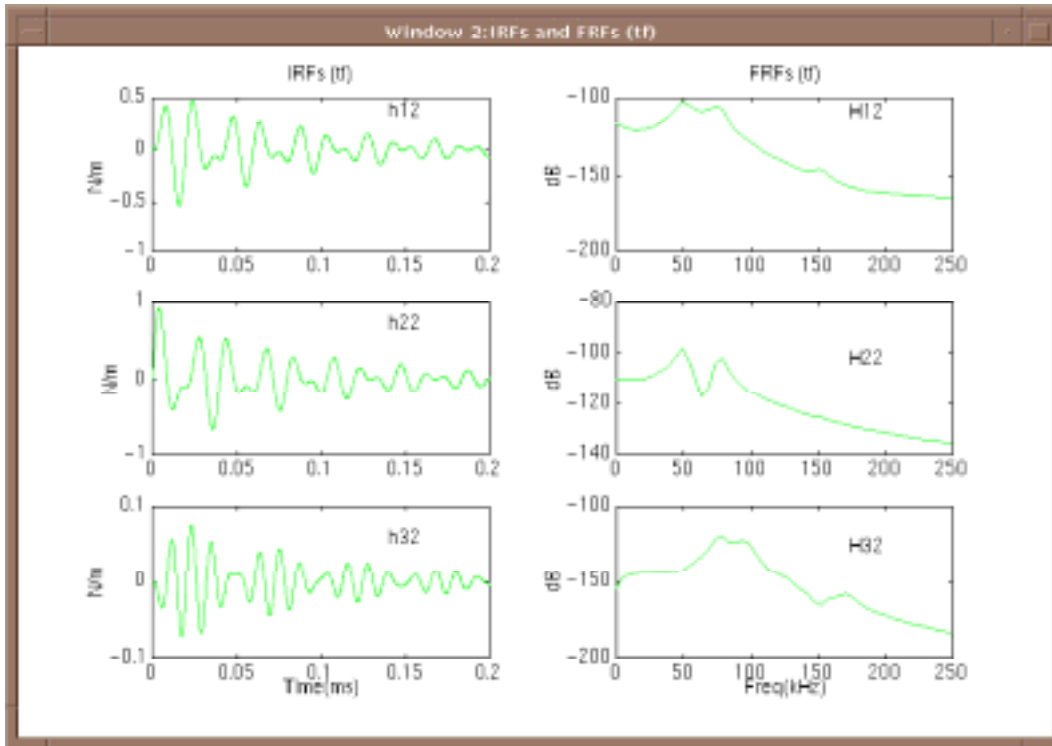


Figure 7 IRFs and FRFs for the excitation in the pitch direction

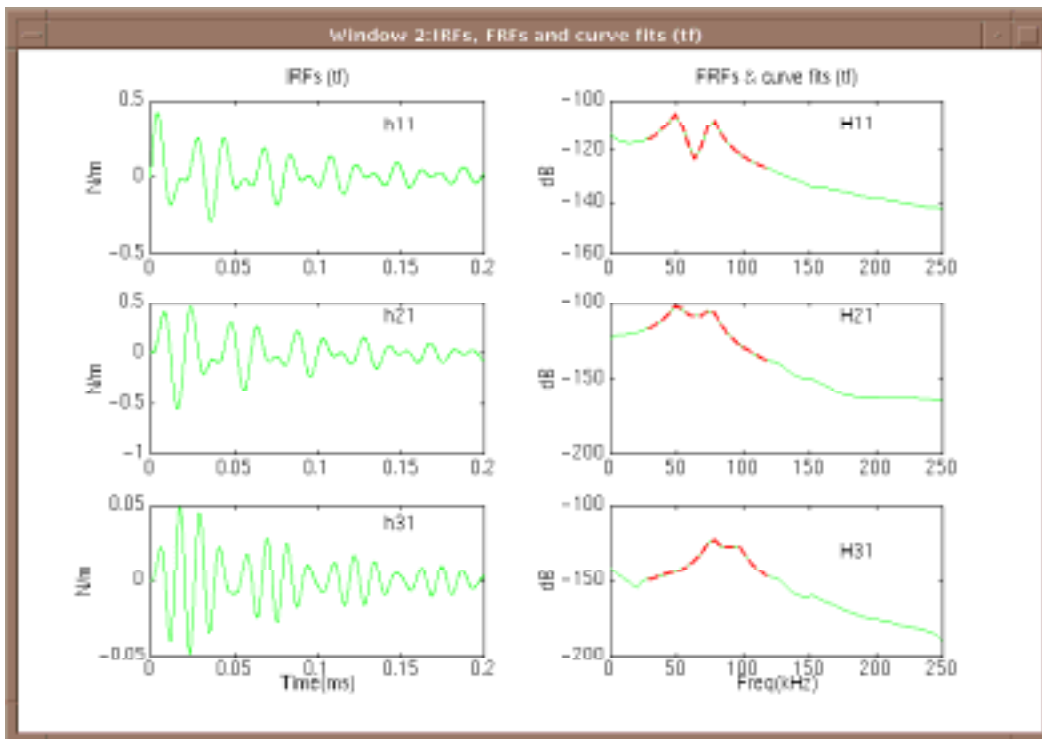


Figure 8 IRFs, FRFs and curve fits for the excitation in the vertical direction

Window 2: Results table (tf)						
Results Table						
Name: tf	Flying height=48.06 nm					
Mode	1	2		3		
Freq.(kHz)	49.5	76.06		96.16		
Damp(%)	3.928	1.917		2.019		
	Amp.	Phase	Amp.	Phase	Amp.	Phase
	3.632e-01	-0.31	3.034e-01	-178.72	2.059e-02	-179.47
	6.194e+02	0.00	4.849e+02	-0.00	3.272e+01	-0.92
	1.671e+00	93.60	6.852e+01	177.90	7.807e+02	0.00
	Physical Matrices			Updated Matrices		
	5.87e-06	1.93e-11	-3.18e-12	5.952e-06	-8.419e-27	2.042e-27
Mass	1.93e-11	2.15e-12	2.75e-15	8.260e-26	2.176e-12	-3.537e-28
	-3.18e-12	2.75e-15	1.35e-12	-2.884e-26	-3.393e-28	1.361e-12
	9.66e+05	-2.32e+02	-2.21e+01	9.803e+05	-2.381e+02	-2.099e+01
Stiff.	-2.32e+02	3.45e-01	1.31e-02	-2.381e+02	3.507e-01	1.361e-02
	-2.21e+01	1.31e-02	4.92e-01	-2.099e+01	1.361e-02	4.958e-01
	1.799e-01	-1.047e-05	-2.065e-06	1.546e-01	1.092e-05	-3.676e-06
Damp.	-1.047e-05	4.606e-08	1.937e-09	1.092e-05	3.716e-08	2.922e-09
	-2.065e-06	1.937e-09	3.260e-08	-3.676e-06	2.922e-09	3.281e-08

Figure 9 Result table

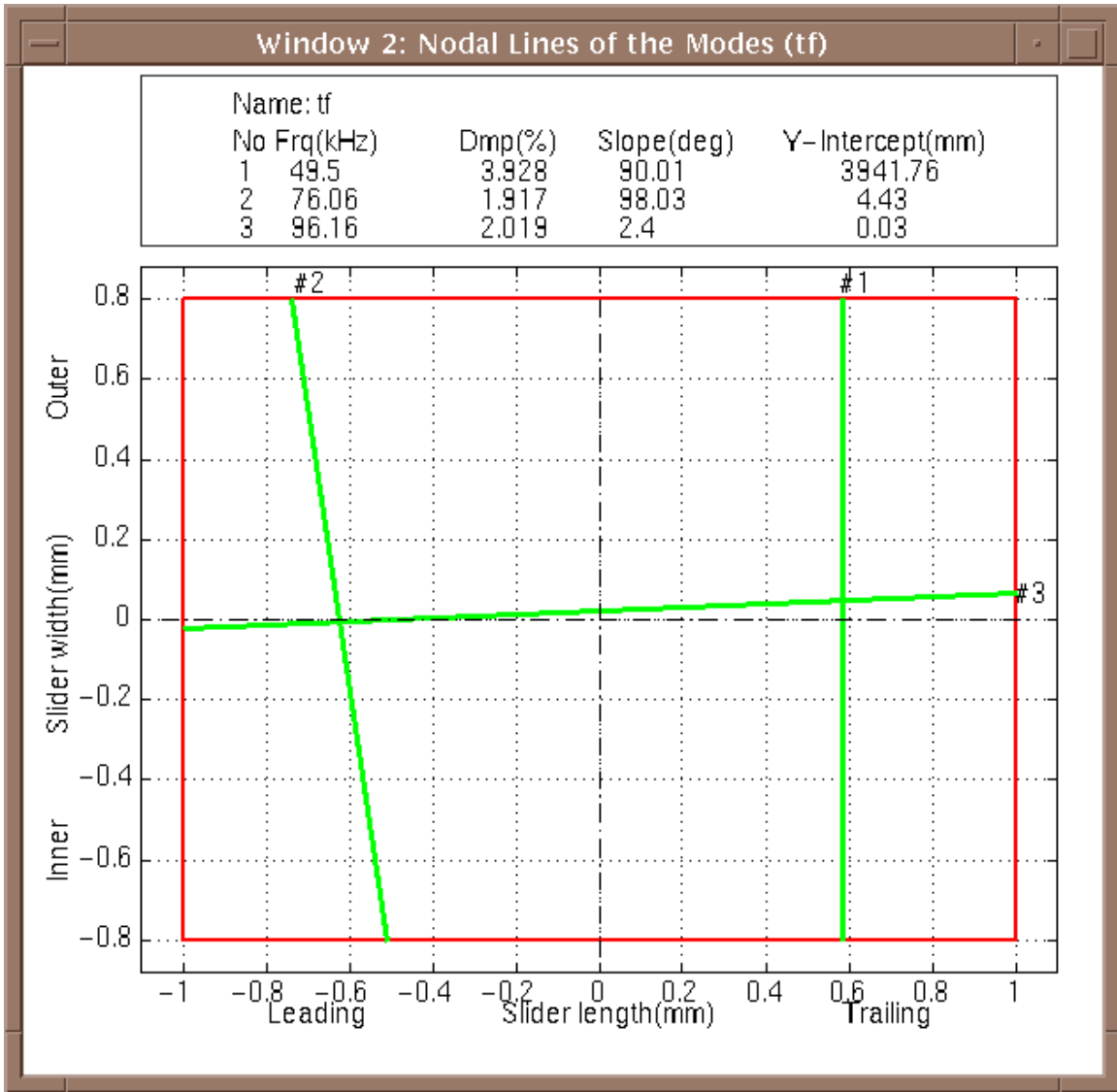


Figure 10 Nodal line displayed with a full table

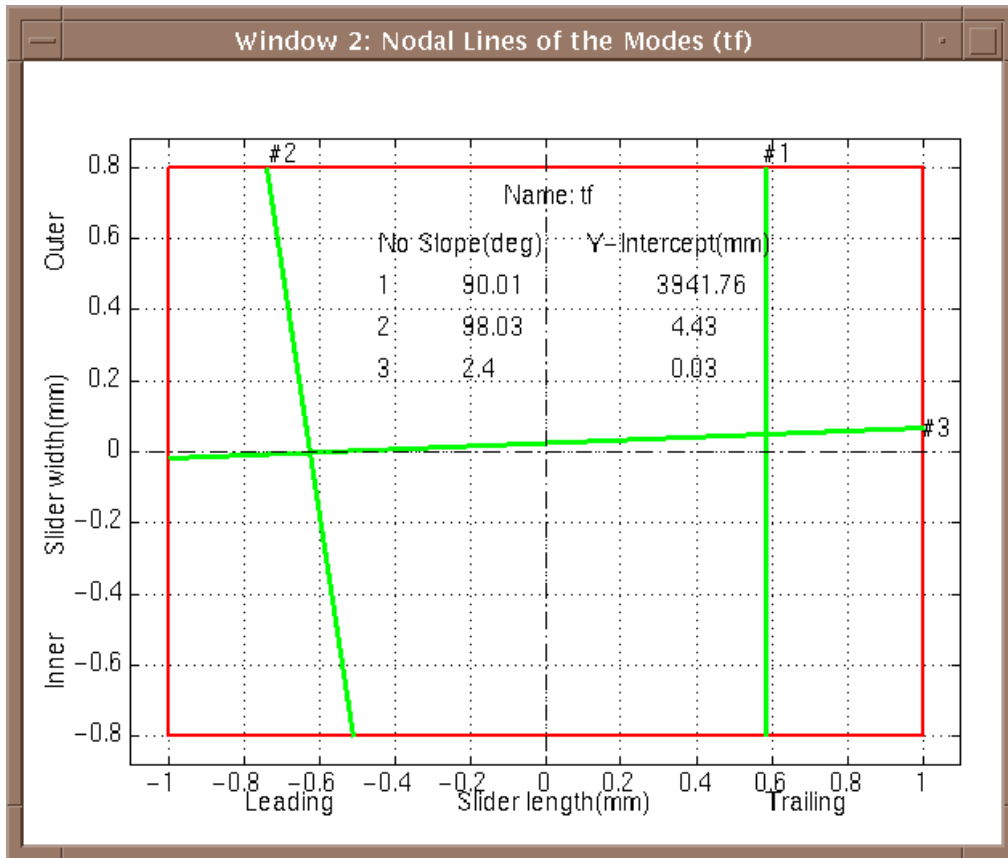


Figure 11 Nodal line displayed with a full table

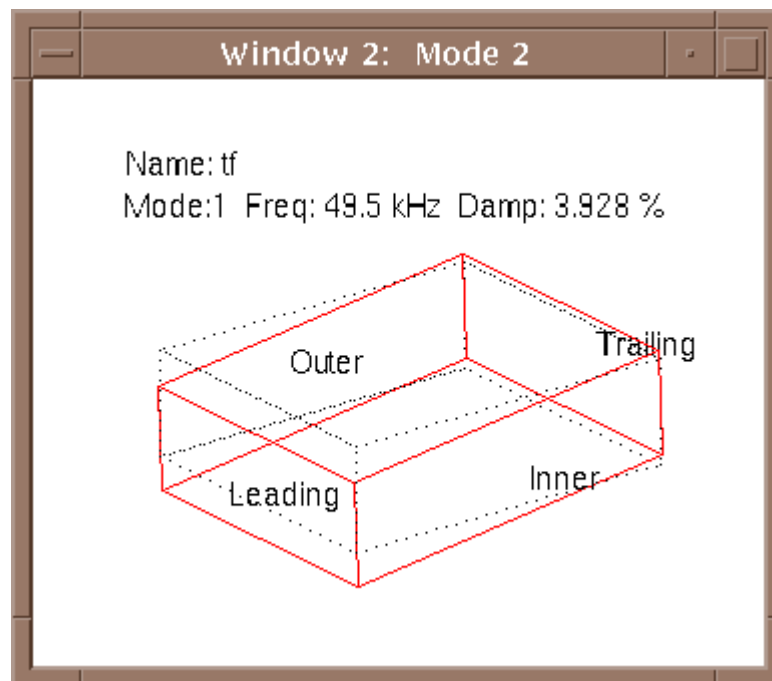


Figure 12 Mode shape animation