

CMLAir Heat Assisted Magnetic Recording system's User Manual

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1. The CMLAir-HAMR system – an introduction

Successful Heat Assisted Magnetic Recording (HAMR) performance depends on the ability of the laser delivery system located in the slider to heat up the magnetic media to its Curie temperature, around 500°C for FePt HAMR media. So with the disk heated to several hundreds of degrees above ambient temperature within the short time window that the hot NFT passes over the disk, it is unjustified to assume the air bearing, which is subjected to the same relative slider velocity as the disk, is still isothermal at ambient temperature.

The HAMR laser delivery system is made up of several components in series that confine the energy of a 700-850-nm laser beam (electromagnetic waves) down to an intensity profile spot on the magnetic media less than 100-nm FWHM to generate the thermal spot required for HAMR writing. The source of the electromagnetic wave is a laser diode separate from the slider or possibly mounted on to the back side of the slider, i.e. the side opposite the ABS. The laser beam is focused using traditional optical means onto the end of a waveguide. The waveguide confines the energy and delivers it to the near-field transducer (NFT). The waveguide is made of a dielectric material assumed to transfer the electromagnetic energy without absorbing significant energy. At the surface of the metallic NFT, it is conjectured that the incident optical field excites surface plasmons, which are collective oscillations of electrons.

The oscillating charges generate an electric field whose intensity exponentially decays with distance from the interface [7]. These oscillations coupled with the electrons in the magnetic media in close proximity and transfer energy. The components likely to dissipate significant amounts of energy are the NFT, the laser diode, and the write pole.

There are static and dynamic versions of CMLAir-HAMR. The static version is called “Iterative Static HAMR”, which we will shorten it to “Static-HAMR” throughout this manual. It consists of three parts: Input files, program files and output files as shown in Figure 3. Program files contain a set of macros written in ANSYS Parametric Design Language (APDL), and the Static-HAMR solver executable file. These macros pass boundary conditions between ANSYS and “Static-HAMR solver”. Static-HAMR solver is based on ‘CML TFC’ code [8]. The short term for Thermal Flyheight Control is TFC, while Flyheight is FH. Both TFC and FH

acronyms will be used often in this manual. Static-HAMR can be partnered with the finite element solver ANSYS to create an iterative static solver that solves the coupled sliders flying attitude and thermal deformation problems as described in Section 2.

The other version of the CMLAir-HAMR is the Dynamic CMLAir HAMR, which we will call it “Dynamic-HAMR” in this manual. A detailed description of this version will be presented in a later section.

2. Static-HAMR

The flying attitude and thermal deformation solutions of a TFC slider or HAMR slider must be solved by an iterative approach. The air bearing and slider thermal deformation solutions are related to each other through boundary conditions at the ABS (heat transfer coefficient and pressure, temperature and protrusion). Static-HAMR solver predicts the pressure profile and flying attitude of a slider for a given suspension load, slider thermal protrusion profile, and the ABS temperature profile, a new feature for the Static-HAMR solver. The thermal protrusion due to specified heat generating components can be determined from a finite element solver such as ANSYS where the heat transfer boundary conditions and the pressure force at the air bearing surface depend on the slider's flying attitude and pressure profile.

Figure 1 shows the flowchart of the Static-HAMR procedure. The first Static-HAMR case is solved to obtain an initial pressure profile and spacing profile (FH) under the slider. The heat transfer coefficient at the ABS surface is calculated according to Equation 1. The heat transfer coefficient and pressure profile are boundary condition inputs to the coupled field analysis performed in ANSYS. The user specifies the TFC heater power and the amount of heat dissipated in the laser delivery system components. The updated ABS protrusion and temperature profiles are inputs into the next Static-HAMR simulation, and updated pressure and spacing profiles are obtained. The iterations between ANSYS and Static-HAMR solver continue until the nominal FH (FH at the trailing edge center) obtained from two consecutive iterations is within a specified tolerance.

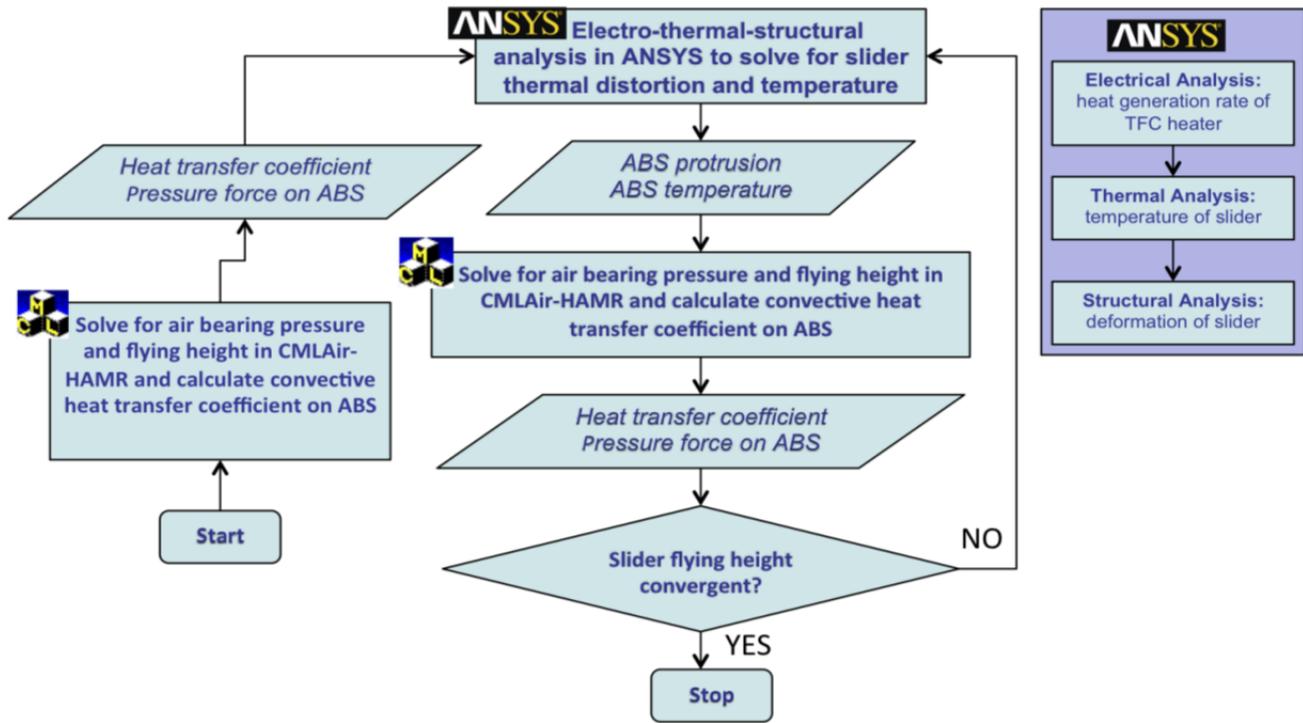


Figure 1. Static-HAMR algorithm [9]

3. Dynamic-HAMR

Dynamic-HAMR is a modification of Dynamic CMLAir for non-isothermal conditions expected for HAMR sliders. Dynamic-HAMR predicts the slider's flying attitude (FH, pitch and roll angles) that is the result of the air bearing force that balances a given suspension. This air bearing simulation code includes the effects of both thermal protrusion and elevated temperatures due to heating elements incorporated into the slider (TFC heaters and laser-delivery system components such as the near-field transducer NFT).

Since Dynamic -HAMR is derived from Dynamic CMLAir, it requires the same input files as the CMLAir Dynamic solver, along with the special input files needed to define input conditions to run Dynamic-HAMR simulations. The list of input and output files will be provided and discussed in detail in a later section of this manual.

4. New features added to the solvers

There are three major changes made to Static and Dynamic CMLAir to create CMLAir-HAMR system:

- Governing air bearing equation: The original CMLAir solves Fukui and Kaneko's air bearing equation that is simplified for isothermal conditions:

$$\sigma \frac{\partial(PH)}{\partial \tau} + \frac{\partial}{\partial X} \left(\Lambda_x PH - PH^3 \bar{Q}_p \frac{\partial P}{\partial X} \right) + \frac{\partial}{\partial Y} \left(\Lambda_y PH - PH^3 \bar{Q}_p \frac{\partial P}{\partial Y} \right) = 0 \quad \dots\dots\dots 1$$

For CMLAir-HAMR, the more general air bearing equation that does not assume isothermal conditions is used. With this form of the equation, the effect of localized air bearing heating due to the heater and a hot NFT can be included.

$$\sigma \frac{\partial}{\partial \tau} \left(\frac{PH}{\bar{T}} \right) + \frac{\partial}{\partial X} \left(\Lambda_x \frac{PH}{\bar{T}} - \frac{PH}{\bar{\mu}\bar{T}} \bar{Q}_p \frac{\partial P}{\partial X} + \frac{P^2 H^3}{\bar{\mu}\bar{T}^2} \bar{Q}_r \frac{\partial \bar{T}_w}{\partial X} \right) + \frac{\partial}{\partial Y} \left(\Lambda_y \frac{PH}{\bar{T}} - \frac{PH}{\bar{\mu}\bar{T}} \bar{Q}_p \frac{\partial P}{\partial Y} + \frac{P^2 H^3}{\bar{\mu}\bar{T}^2} \bar{Q}_r \frac{\partial \bar{T}_w}{\partial Y} \right) = 0 \quad \dots\dots\dots 2$$

See References 1-4 and 9 for more information about the air bearing equation and the specifics of its implementation into CMLAir-HAMR.

- Flow rate coefficient evaluation method: An improved technique to evaluate the flow rate coefficients, QP (Poiseuille flow) and QT (thermal creep flow), is implemented. This method uses a Chepychev polynomial expansion to evaluate the Abramowitz function that appears in the variational results for the flow rate coefficients, and it is accurate for both QP and QT [1]. The piecewise asymptotic expansion and power series approximation method implemented in the original CMLAir is sufficiently accurate for QP but unacceptably inaccurate for QT for Knudsen numbers of order unity.
- Independent time variation of ABS temperature and protrusion: Jinglin Zheng developed the ability to study TFC slider touch down dynamics by using a time-varying protrusion profile within the dynamic version of CMLAir [6]. However, this feature has not been incorporated in any previous release versions of CMLAir. For the Dynamic-HAMR, time-varying ABS protrusion as well as temperature can be specified independently of each other. This may be relevant because the thermal response of the NFT could be much faster than the protrusion response [5].

5. Input Files

➤ Static-HAMR Input Files:

The Static-HAMR solver requires some of the same input files as the original CMLAir static code. These common input files for Static-HAMR solver are rail.dat and run.dat. In the run.dat file, we added icreep and icheby to “Solution Control” section.

icheby: 1 = use Chebyshev polynomial expansion of the Abramowitz function to evaluate QP; 0 = use the piecewise asymptotic expansion and power series approximation of the Abramowitz function method to evaluate QP

icreep: 1 = include the thermal creep effect in the governing air bearing equation; 0 = ignore thermal creep

See the original CMLAir static code documentation for the format of these files. Additionally, you need the following input files:

- TFCrun.dat: It contains input parameters for the HAMR system as well as instructions for ANSYS. The sample file below (Figure 2) shows the TFC and HAMR parameters. There you can control heater, NFT and laser diode power respectively. This is the same file as the TFC Code’s TFCrun.dat with the addition of the ‘NFT’ and ‘laser diode’ sections.

```
db file name
*****
HAMRslider_simple

thermal model
*****
ModelType
2

ansys model
*****
unit orient
2 1
pad1 pad2
13 15
refTemp(C)
25

heater
*****
power(mW) res(ohms)
10 5
```

```
NFT
*****
NFTvolu power(mW)
  2      1

laser diode
*****
diodeVolu power(mW)
  8        0

mapping
*****
xmin  xmax
0.6   1
ymin  ymax
0.25  0.75
nx    ny
401   401

constraints
*****
backfixed
1

loads
*****
pres
0

cooling
*****
back side (W/(m.m.k))
2000   100

convergence
*****
criterion limit(nm)
1       0.05
Max. num. of Iteration
15

air parameters
*****
Kair(W/(m.K)) gamma Pr sigma_T
2.62e-2      1.4015 0.7145 1.0
```

Figure 2. Sample of TFCrun.dat

- ANSYS model file (.db): This database is required for ANSYS software to run. It contains the 3-D geometry and material property information of the slider block.
- UserGeom01.dat: User-defined ABS protrusion that is added to the defined rail design from rail.dat. UserGeom01.dat is the base profile due to TFC heater protrusion and/or laser delivery system induced protrusion. UserGeom01.dat can also be detailed reader-writer protrusion beyond main heater bulge. This file will be updated according to the most current ANSYS iteration during the runtime of the Static-HAMR code.
- Ts01.dat: User-defined ABS temperature. Ts01.dat is the base ABS temperature profile due to the TFC heater and/or laser-delivery system components. This file will be updated according to the most current ANSYS iteration during the runtime of the Static-HAMR code.
- ANSYS macro files: There are five macro files written in APDL. Those files run the ANSYS analysis, call the Static-HAMR solver, and check for convergence. Macros, input and output files are shown in Figure 3.

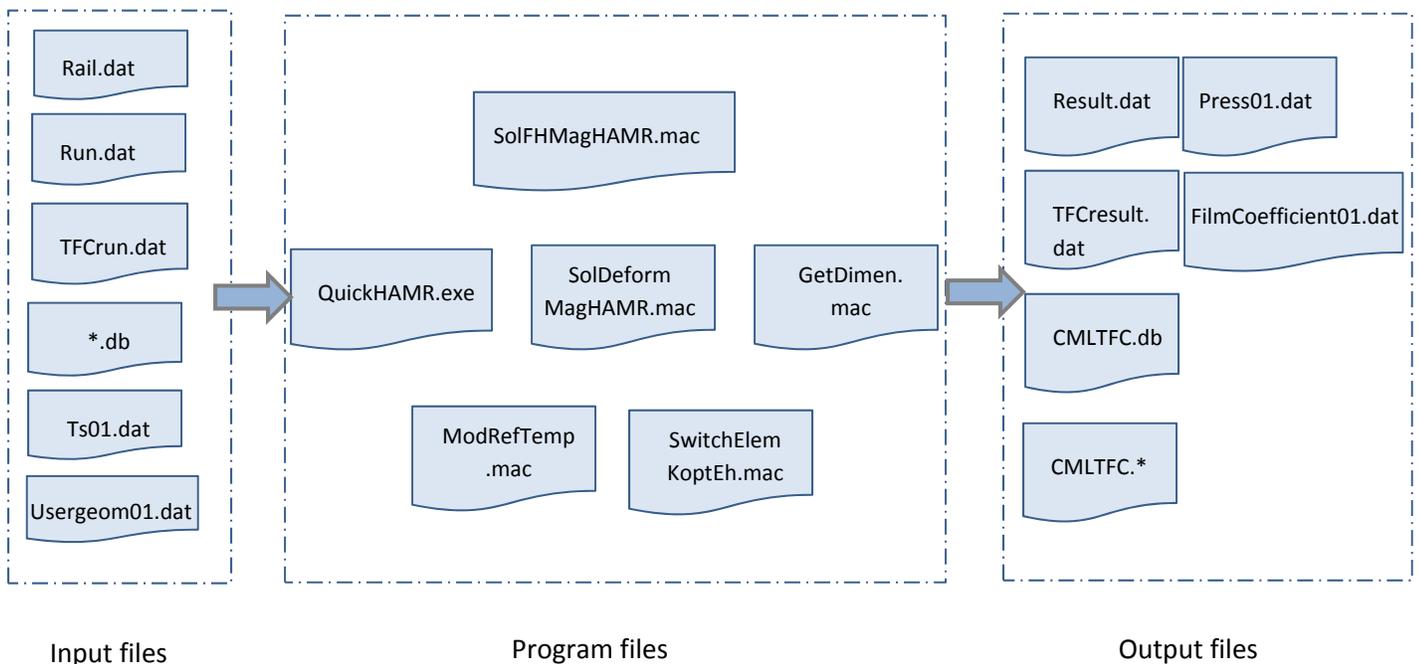
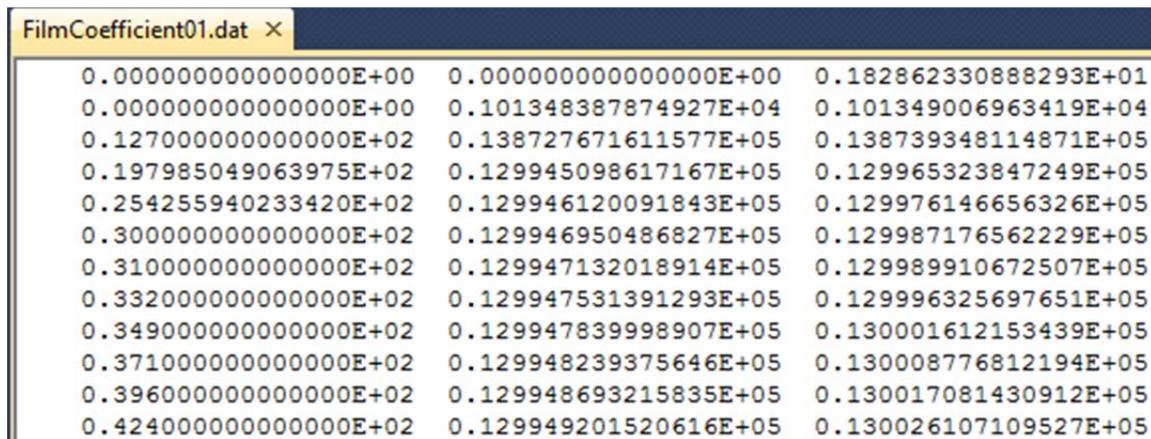


Figure 3. Static-HAMR file structure

➤ Dynamic-HAMR input files:

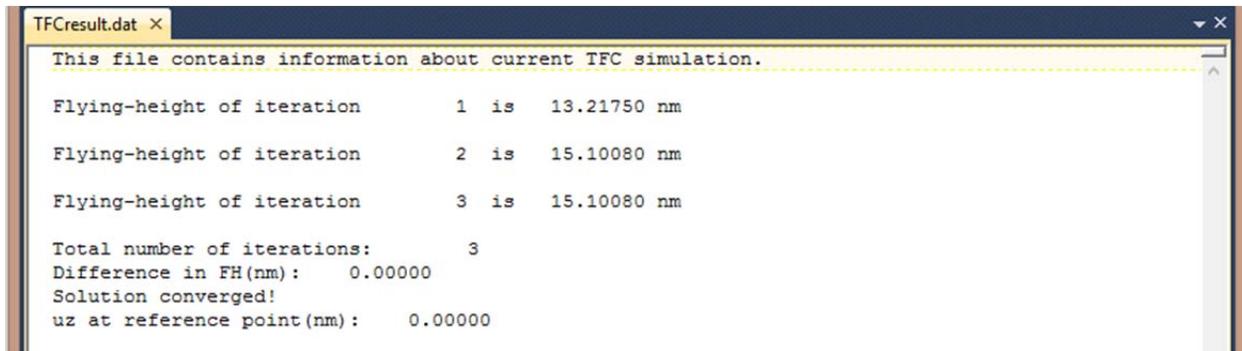
The input files for the Dynamic-HAMR are the same as for the Dynamic CMLAir code, except minor changes in dynamic.def file where we added icreep and icheby to “Solution Control” section. The following files are newly added:

- UserGeom01.dat: User-defined ABS protrusion that is added to the defined rail design from rail.dat. UserGeom01.dat is the base profile due to TFC heater protrusion and/or laser delivery system induced protrusion that will be interpolated as specified in UserGeomProfile01.dat to simulate a changing ABS protrusion. UserGeom01.dat can also describe detailed reader-writer protrusion beyond main heater bulge. UserGeom01.dat is typically an ABS protrusion determined by the Static-HAMR Solver.
- Ts01.dat: User-defined ABS temperature. Ts01.dat is the base ABS temperature profile due to the TFC heater and/or laser-delivery system components. Ts01.dat is typically an ABS protrusion determined by the Static-HAMR solver from the same simulation as UserGeom01.dat.
- UserGeomProfile01.dat: Describes how the protrusion profile defined in UserGeom01.dat changes in time. The user provides the radius of the Gaussian interpolation function centered at the peak location and the ratio of desired peak protrusion to the peak protrusion in UserGeom01.dat at specified time points. Between specified time points, the peak protrusion can vary linearly or with a more abrupt, but still smooth, step-like change.
- TsProfile01.dat: Same format as UserGeomProfile01.dat to prescribe the ABS maximum temperature variation and Gaussian interpolation function.



FilmCoefficient01.dat ×		
0.0000000000000000E+00	0.0000000000000000E+00	0.182862330888293E+01
0.0000000000000000E+00	0.101348387874927E+04	0.101349006963419E+04
0.1270000000000000E+02	0.138727671611577E+05	0.138739348114871E+05
0.197985049063975E+02	0.129945098617167E+05	0.129965323847249E+05
0.254255940233420E+02	0.129946120091843E+05	0.129976146656326E+05
0.3000000000000000E+02	0.129946950486827E+05	0.129987176562229E+05
0.3100000000000000E+02	0.129947132018914E+05	0.129989910672507E+05
0.3320000000000000E+02	0.129947531391293E+05	0.129996325697651E+05
0.3490000000000000E+02	0.129947839998907E+05	0.130001612153439E+05
0.3710000000000000E+02	0.129948239375646E+05	0.130008776812194E+05
0.3960000000000000E+02	0.129948693215835E+05	0.130017081430912E+05
0.4240000000000000E+02	0.129949201520616E+05	0.130026107109527E+05

Figure 4. FilmCoefficient.dat sample



```
TFCresult.dat x
This file contains information about current TFC simulation.

Flying-height of iteration      1 is 13.21750 nm
Flying-height of iteration      2 is 15.10080 nm
Flying-height of iteration      3 is 15.10080 nm

Total number of iterations:      3
Difference in FH(nm):      0.00000
Solution converged!
uz at reference point(nm):      0.00000
```

Figure 5. TFCresult.dat sample

6. Output files

➤ Static-HAMR output files

The Static-HAMR solver produces all of the standard output files of the CMLAir quick4 solver, such as result.dat, press01.dat, etc. In addition, the file named FilmCoefficient01.dat tabulates the air bearing cooling coefficients applied into the ANSYS finite element model. Figure 4 gives a sample of this file. The first row of FilmCoefficient01.dat gives the coordinates in the ANSYS model along the slider's length direction, and the first column lists the coordinates in the ANSYS model along the slider's width direction.

CMLTFC.db is the originally input *.db file with all loads applied and solution saved. Therefore, you can obtain all post-processing results provided by ANSYS through this file, including the displacements, temperature, stress, heat flux, etc. Moreover, all the usual accompanying ANSYS files are in the working directory. These can be checked for essential running information or ANSYS convergence issues. For example, you may want to check CMLTFC.err for any warning and error messages. Refer to ANSYS help for details of these files.

TFCresult.dat file contains progress towards the convergence criterion specified in the 'convergence' section of TFCrun.dat. You can access this file throughout the running process to learn the progress of the solution. The file is comprised of two parts: information of the converging process and a summary of results, as shown in Figure 5. The first part lists the nominal FH or point of interest calculated from iterations that are finished. The second part contains information about the total number of iterations, the difference in the nominal FH of the last two iterations, whether the solution is

considered to be converged, and the deformation (UZ) at the reference point. Here, if the solution converges in the specified maximum iteration number, a message of solution converged will be written in this file. Otherwise, a message of solution not converged will be given in this file.

Finally, Usergeom01.dat contains information about the slider deformation at the mapping area specified in TFCrun.dat. It is of the same format as user defined geometry defined in CMLAir. Refer to CMLAir user manual for the format of this file. Throughout the simulation process, UserGeom01.dat and Ts01.dat get overwritten by the Static-HAMR solver in each iteration. Once the iterative solution has converged, those files contain the final answers for the ABS deformation and temperature for the given heater, NFT and laser diode parameters.

➤ **Dynamic-HAMR output files**

The list below is the output files created by Dynamic-HAMR. Many are the same as for the original dynamic CMLAir code.

- **aload.dat:** This file has the combined air-bearing and Van der Waals forces. It contains 6 columns; Time step, normalized force per time step, center of force from pressure in the x direction, center of force from pressure in the y, positive force and negative forces respectively.
- **abload.dat:** This file has air-bearing forces only, separated from Van der Waals forces. It has 4 columns; Time step, normalized air-bearing force, force in the x direction and force in the y direction respectively.
- **imfload.dat:** This file has only intermolecular forces (Van der Waals) only. It has 4 columns; Time step, normalized force, force in the x and force in the y direction respectively.
- **g_udgt0.dat:** This file contains the initial normalized slider deformation for each point in the mapping grid. In other words, it contains the slider deformation information contained in UserGeom01.dat but as a normalized protrusion and is interpolated on the CMLAir grid instead of the regular grid defined in UserGeom01.dat. The normalizing quantity is h_m , the initial nominal FH specified by the user in dynamic.def.

- `maxABStemp.dat`: This file contains the peak ABS temperature in Celsius for each time step.
- `peakProtrusion.dat`: This file contains the peak protrusion of the slider for each time step. The unit for Time is seconds, and the unit for protrusion is nanometers.
- `FKdbase_methods.dat`: This file contains the flow rate coefficient database that is calculated for a range of Knudsen numbers and is interpolated during the run of the code to determine the local flow rate coefficients. The four columns contain the inverse Knudsen number (z), the Poiseuille flow coefficient (q_n) as calculated using a piecewise asymptotic expansion and power series approximation method for the Abramowitz function (original CMLAir method), and the Poiseuille (q_p) and thermal creep (q_t) flow rate coefficients calculated from a Chebyshev polynomial expansion of the Abramowitz function.

7. Setup and Operation

Since setup and operation are different for Static-HAMR than for Dynamic-HAMR, we will talk briefly about each case separately.

- **Iterative Static-HAMR:** It is basically a CML TFC solver with HAMR functionality added. You can run it by copying all required input files along with the Static-HAMR solver executable file to a folder, then open ANSYS APDL launcher software, navigate to the folder, run the following ANSYS command (invoking the main ANSYS macro) in the ANSYS command prompt: **USE, SolFHMmagHAMR.mac*
- **Dynamic-HAMR:** This executable is a CML Dynamic solver with HAMR functionality added to it. You can run it by copying all input files along with the Dynamic-HAMR solver executable file to a common folder, and run the executable via the command prompt or double click the solver, just like running a CML Dynamic code.

8. Example cases

In this document, two example cases are described. One for static HAMR, while the other one is for dynamic HAMR. Simulations have been done using the “HAMR” slider shown in Figure 6 to demonstrate the effects of various slider components in the HAMR system. Different temperature and user defined geometry profiles have been used for the static and dynamic HAMR cases. Figure 7-a shows the predefined temperature distribution in the defined region of the slider used for the Static-HAMR case. The maximum temperature shown is 175° C. This temperature profile is contained in Ts01.dat and can be modified from the text file. Figure 7-b shows the user defined geometry contained in UserGeom01.dat for the same slider region used for the Static-HAMR case study. Maximum protrusion shown is 7 nm. You can modify it by editing UserGeom01.dat file. Figures 8-a and 8-b show temperature (Ts01.dat) and user defined geometry profiles (UserGeom01.dat) respectively for the Dynamic-HAMR case. The maximum temperature shown in figure 8-a is 275° C, while maximum protrusion is 14 nm.

In the next section, the results from both HAMR solvers will be discussed in detail.

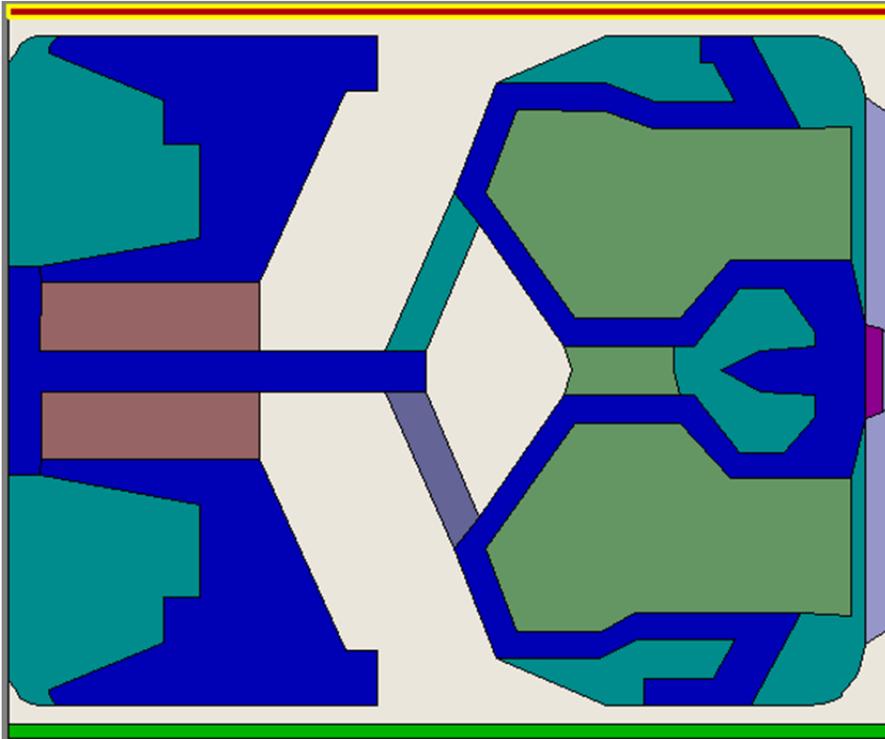


Figure 6. HAMR slider design used in simulations

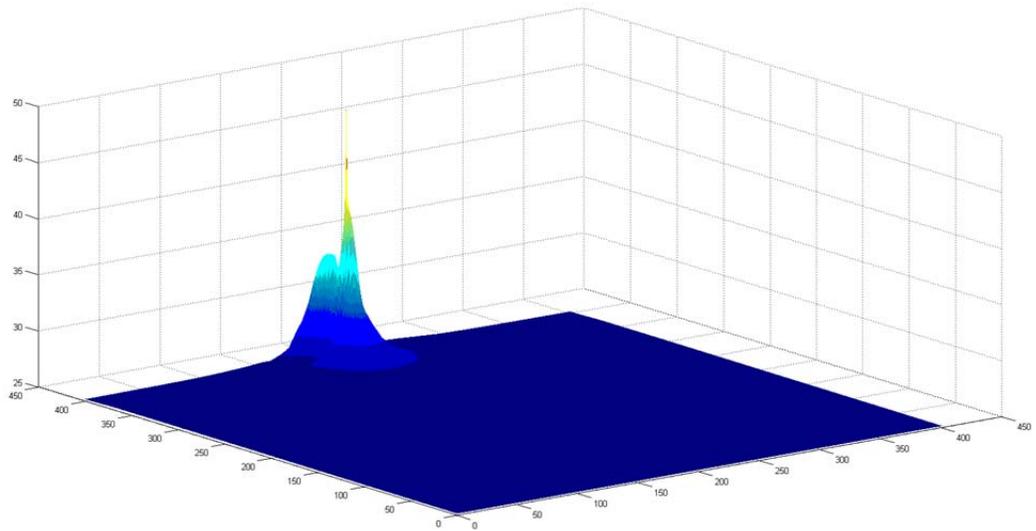


Figure 7-a. Ts01.dat for Static-HAMR case with heater power = 10mW. Max temperature is 47.6° C.

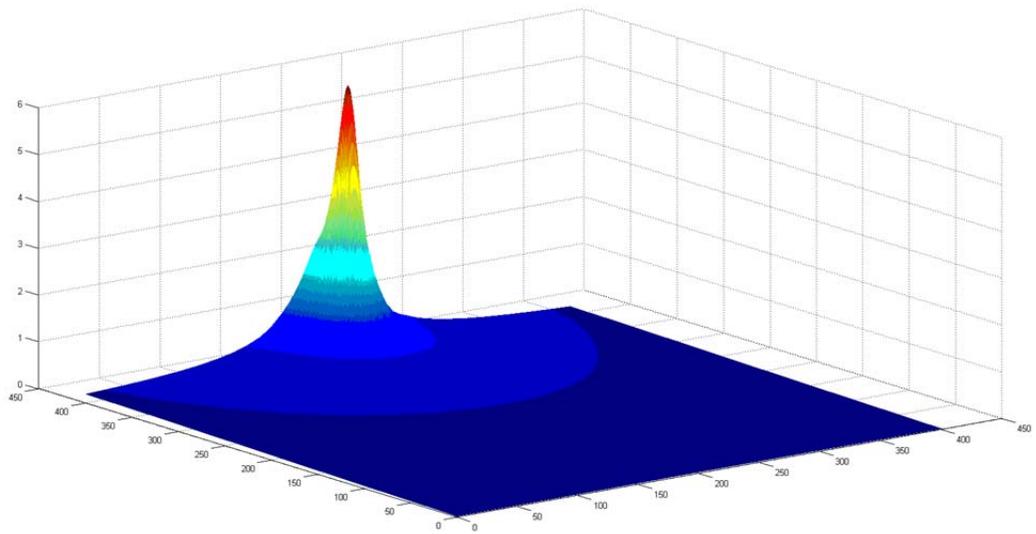


Figure 7-b. UserGeom01.dat for Static-HAMR case for heater power = 10mW. Max protrusion is 5.9 nm.

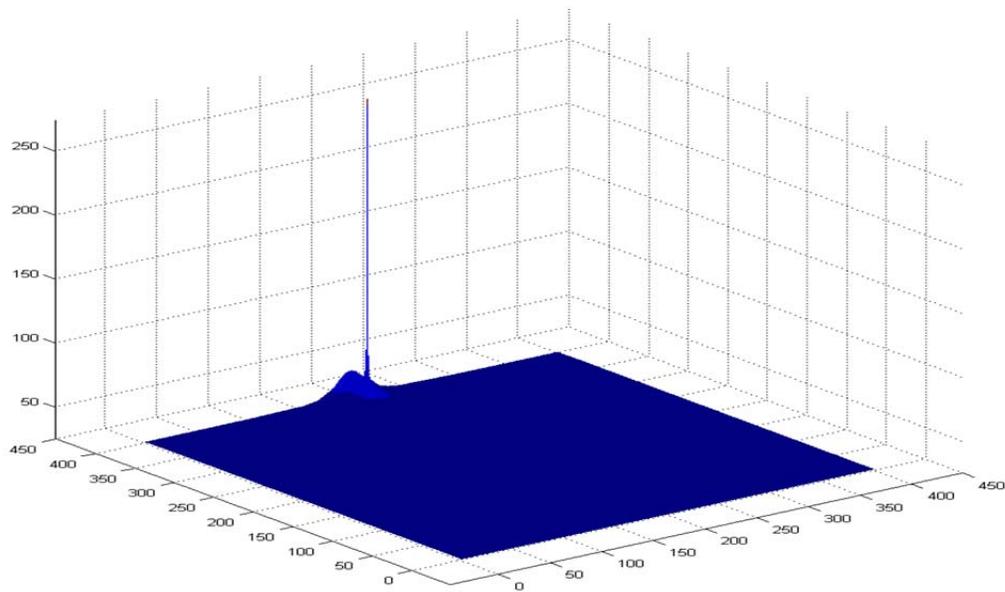


Figure 8-a. Ts01.dat for Dynamic-HAMR case. $dT = 49$. Max temperature is 274.

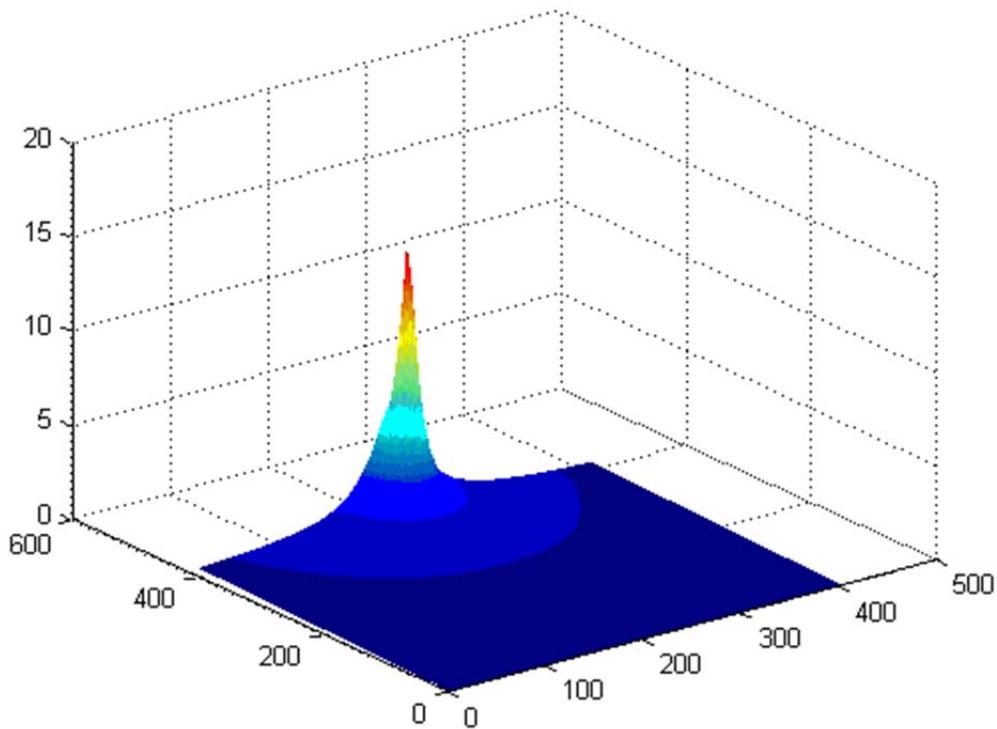


Figure 8-b. UserGeom01.dat for Dynamic-HAMR case. $dT = 49$. Max protrusion is 15.6 nm.

9. Results and discussion

➤ Static-HAMR

In this section, we will address the effects of including multiple elements in the slider finite element model such as: Heater, NFT, wave guide and laser diode. The effects of each element along with accompanying results and figures will be discussed. Firstly, let's start with the heater element.

The effect of the heater is isolated by using an ANSYS slider model that contains only a heater element. There is no NFT, wave guide or laser diode. Effects of changing heater power on Static-HAMR can be seen in Figure 9. It illustrates the relation between the minimum FH in nm for each given heater power input. The more power we apply through the heater the smaller is the minimum FH. The minimum FH at 0 mW heater power equals to 12.6 nm, while its

2.5 nm when heater power is at maximum of 25 mW. This is a typical TFC functionality of the slider when heater power is applied. When the bulge in the slider increases due to the increase in heater power supplied, decrease in FH would be expected.

Next we study an ANSYS slider model that contains: heater, NFT and waveguide. Heater power used varied from 0 mW to 25 mW. Two values of NFT power are demonstrated: 1 and 2 mW. Figure 10 shows effect of changing NFT power on minimum FH of the slider. As we can see from the figure, increasing the NFT power will increase the thermal protrusion of the slider and cause it to fly closer to surface of the disk.

Finally, we discuss the Static-HAMR results for an ANSYS slider model containing all four elements: Heater, NFT, wave guide and laser diode. Results from fixing NFT power at 1 mW and changing laser diode power from 50 to 100 mW are shown in Figure 11. The laser diode power has no significant effect on minimum FH of the slider. Figure 12 shows the minimum FH vs. heater power for all slider model cases.

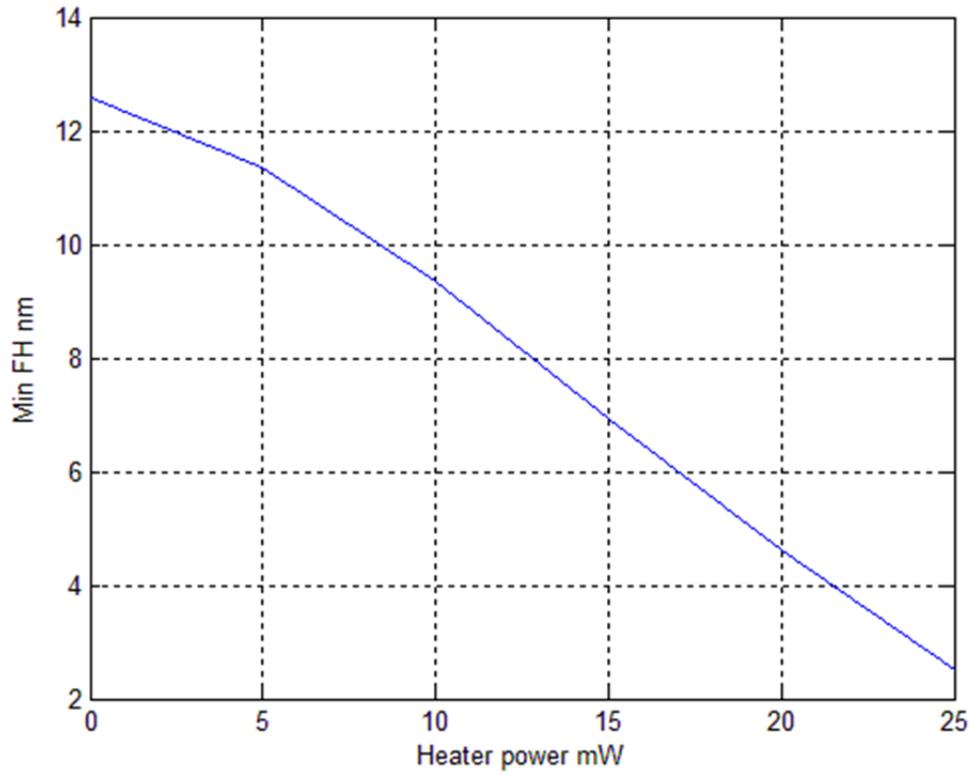


Figure 9. Minimum FH vs Heater power

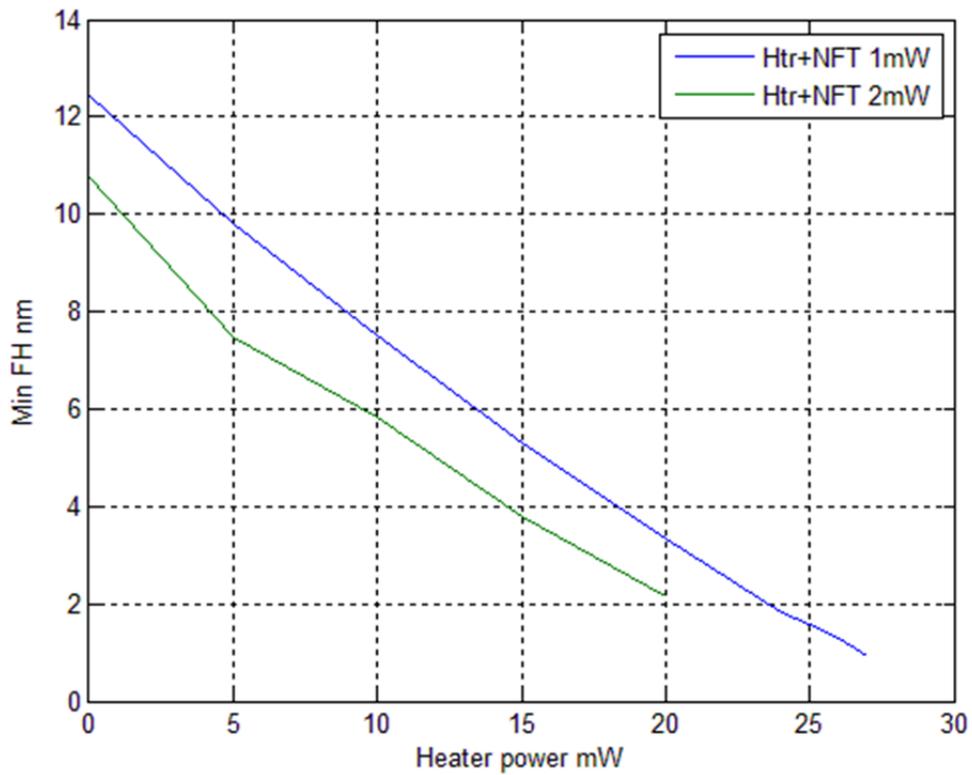


Figure 10. Minimum FH vs Heater power with 1 & 2mW NFT power

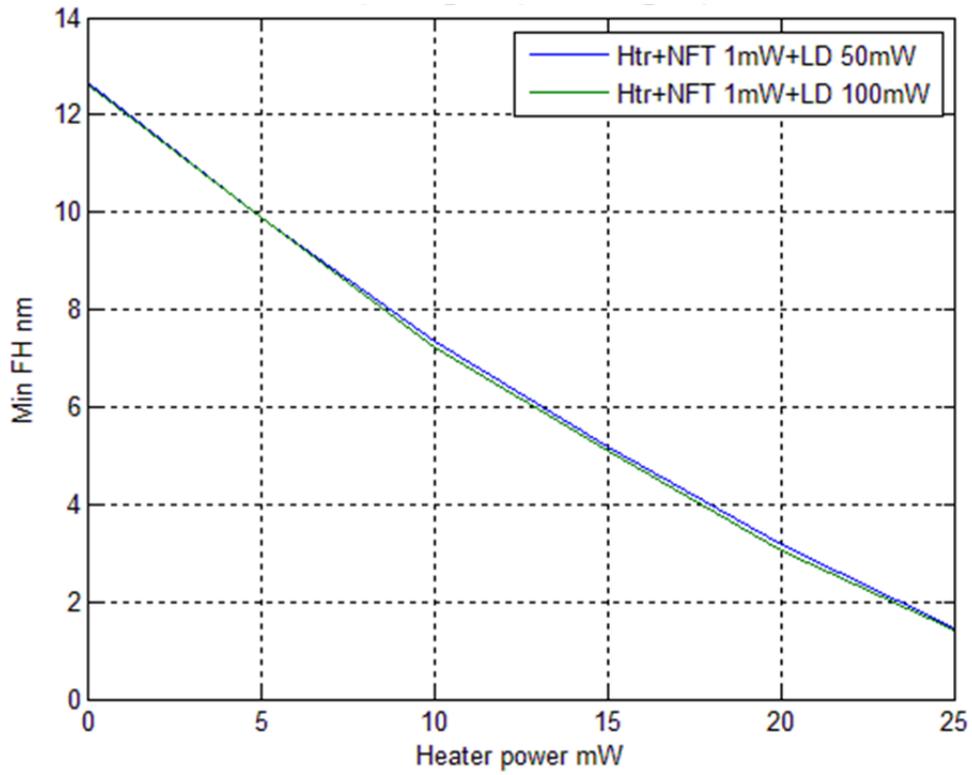


Figure 11. Minimum FH vs Heater power with 1 mW NFT power and 50,100 mW laser diode power

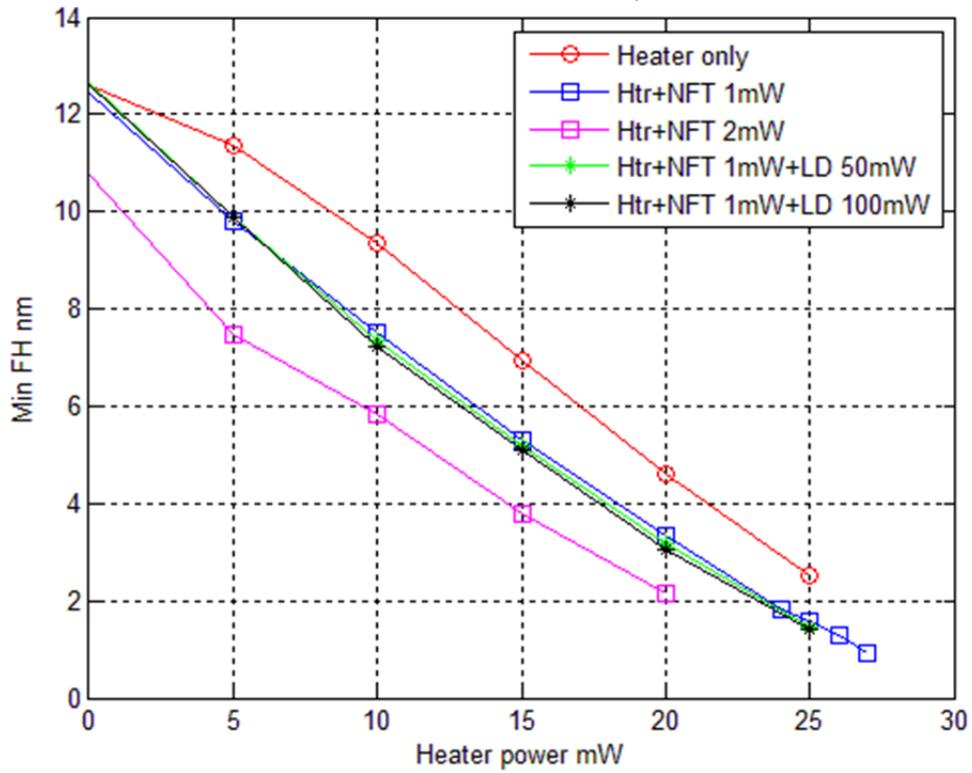


Figure 12. Minimum FH vs Heater power – All cases

➤ **Dynamic-HAMR**

In the next example, we investigate a HAMR system under time-varying boundary conditions using the Dynamic-HAMR. In this section we will address the effects of multiple HAMR slider elements and inputs and to what extent it can change the output results. During these simulations, since Dynamic-HAMR is a time varying process, we decided to take two study cases to illustrate its operation: a rapid step change in the ABS temperature profile such as when the HAMR system laser that energizes the NFT is suddenly turned on (Step case) and a pulsed ABS temperature profile such as when the HAMR system laser is pulsed on and off as the slider flies over servo zones (Pulse case). Furthermore, the user specifies a sharp, yet smooth, or a linear temperature transition between time points. Figure 13 shows two TsProfile01.dat files for both cases. The first row contains three values, σ_x , σ_y and transition time in seconds. σ_x , σ_y are non-dimensional standard deviation of Gaussian interpolation function normalized by the slider length. Suggested values are 200. The second row contains the number of time points (rows) to read. The remaining rows contain the temperature variation information in three columns marked in red rectangles. Column 1 is time points in seconds. Column 2 is the ratio below:

(Desired ABS max T at given time point)/(max T in base profile Ts01.dat)

Column 3 is the ramp or step case. 1 is ramp which means smooth step or linear temperature variation between time points. 0 is step case which means sudden jump in temperature between time steps. For both Step and Ramp cases, multiple time points have been used to prescribe a changing ABS temperature in time. In order to understand the meaning of dT in upcoming figures, the following formula demonstrates how can we calculate it:

dT in the plots = maximum ABS temperature achieved in dynamic simulation – ambient temperature. The ABS temperature specified in Ts01.dat is defined over a regular grid. These specified temperatures are

interpolated onto the Dynamic-HAMR solver grid during the run of the code, and therefore sharp temperature peaks are likely not fully captured within the air bearing solver. To determine the maximum ABS temperature that was interpolated on the Dynamic-HAMR grid, we can look at the maxABStemp.dat output file. For all the cases in this manual and for simplicity, we used 25° C as the ambient temperature in Ts01.dat. Five dT values have been selected here: 0, 49, 94, 138, and 183° C.

Step			Pulse		
200	200	0.0e+00	200	200	0.0e+00
3			414		
0.0000e+00	9.1139e-02	1	0.0000e+00	9.1139e-02	1
0.5e-3	4.5570e-01	1	3.7700e-08	3.7293e-01	1
1.0000e-03	4.5570e-01	1	1.1310e-07	5.3912e-01	1
			1.8850e-07	5.8548e-01	1
			7.5488e-07	6.9385e-01	1
			1.3213e-06	7.2028e-01	1
			1.8876e-06	7.2690e-01	1
			2.4540e-06	7.2856e-01	1
			1.2285e-05	7.2911e-01	1
			2.2116e-05	7.2911e-01	1
			3.1947e-05	7.2911e-01	1
			4.1778e-05	7.2911e-01	1
			4.1828e-05	3.9882e-01	1
			4.1866e-05	3.1183e-01	1
			4.2017e-05	2.1651e-01	1
			4.2843e-05	1.0768e-01	1
			4.3669e-05	9.3333e-02	1

Figure 13. TsProfile01.dat for Step and Pulse cases

Figures 14-18 demonstrate results obtained for the Step case with multiple dT values mentioned above while Figures 19-23 show results for the Pulse case. Figure 14 illustrates the variation in the x coordinate of the center of total pressure force on ABS with time. As we can see the change in total pressure force does not start till time equals 0.5 second. That's when we switch on the system in TsProfile01.dat. Starting from dT = 0° C (flat blue line) all the way to 183° C, the amplitude of the total pressure force increases with increasing dT value. More dT means more heat, more protrusion at the ABS which correlates to a higher pressure. While there is relatively large variation in the x coordinate of the center

of pressure, there is negligible change in the y coordinate as shown in Figure 15. Figure 16 shows the pitch variation in time. The change in the pitch starts at 0.5 s. The pitch decreases when switching on the system, reduces more with increasing the dT, and reaches the minimum at highest dT amount of 183° C. Pitch shows no change with dT = 0° C. Figure 17 shows the roll with respect to time. Roll also decreases when we switch on the system at 0.5 s, decreases more with increasing the dT amount. Figure 18 shows the variation of minimum FH of the slider with time. As we can see in the figure, minimum FH increases with the increase of dT amount. This is to be expected since higher dT amount means higher pressure under slider that pushes it away from the disk. The curves start at t = 0.5 s and minimum FH increases after, except when dT = 0° C, where no change of slider flying attitude is expected for an isothermal slider.

Unlike the behavior of the system in a Step case, Pulse case fluctuations continue as long as we provide the right on and off pulses in TsProfile01.dat file as we can see in the preceding figures. Figure 19 shows the x coordinate of the center of total pressure force on ABS versus time. The difference between Step and Pulse cases is that when running Step case, the perturbation to the system occurs only once and system's initial transient response decays to a new equilibrium condition, while in a Pulsed case you periodically disturbing the system as shown in the figures and no steady equilibrium condition is reached. The flat line of total pressure is when dT is equal to 0° C in the isothermal slider case. The maximum peak pressure is happening when the dT is maximum. Figure 20 shows the y coordinate of the center of total pressure force on ABS versus time. There is almost no visible sign of pressure change in the y direction. Figure 21 shows the pitch versus time. Maximum flat line pitch happening when the dT = 0° C, while minimum pitch occurred when dT is 183° C. Figure 22 shows the roll of the slider with respect to time. As we can see from the figure, the change in the roll is concentrated between 1.9 and 2.0 μrad. Minimum roll occurs when dT is maximum. Finally, Figure 23 shows the minimum FH versus time. For the FH, it's expected to see an increase with the increase of dT.

Step Case

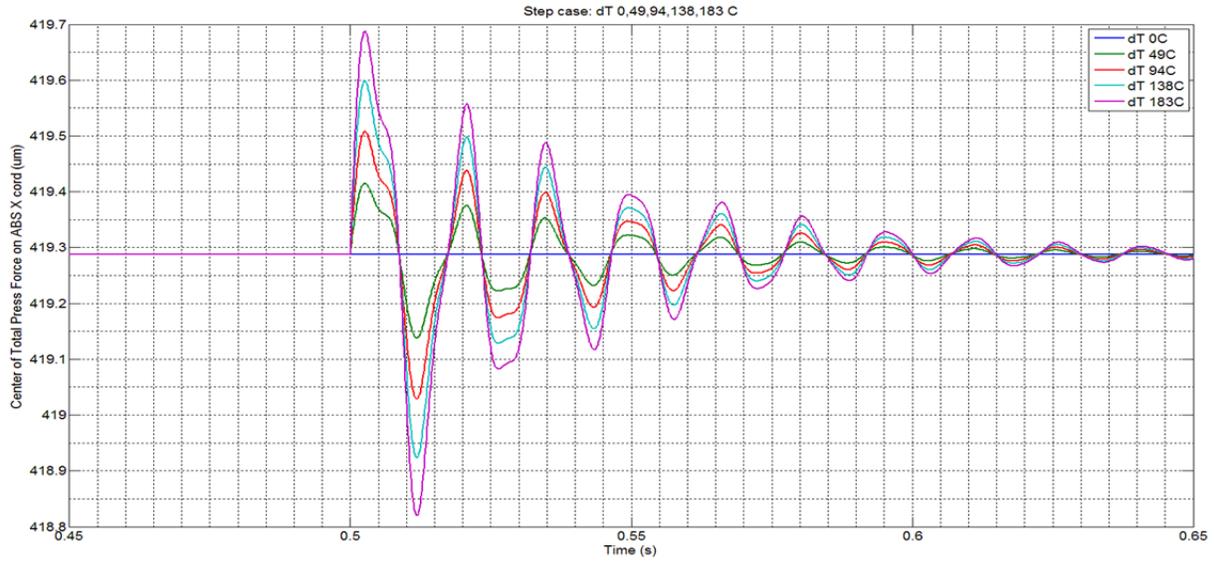


Figure 14. Center of total pressure force on ABS x coordinates versus time

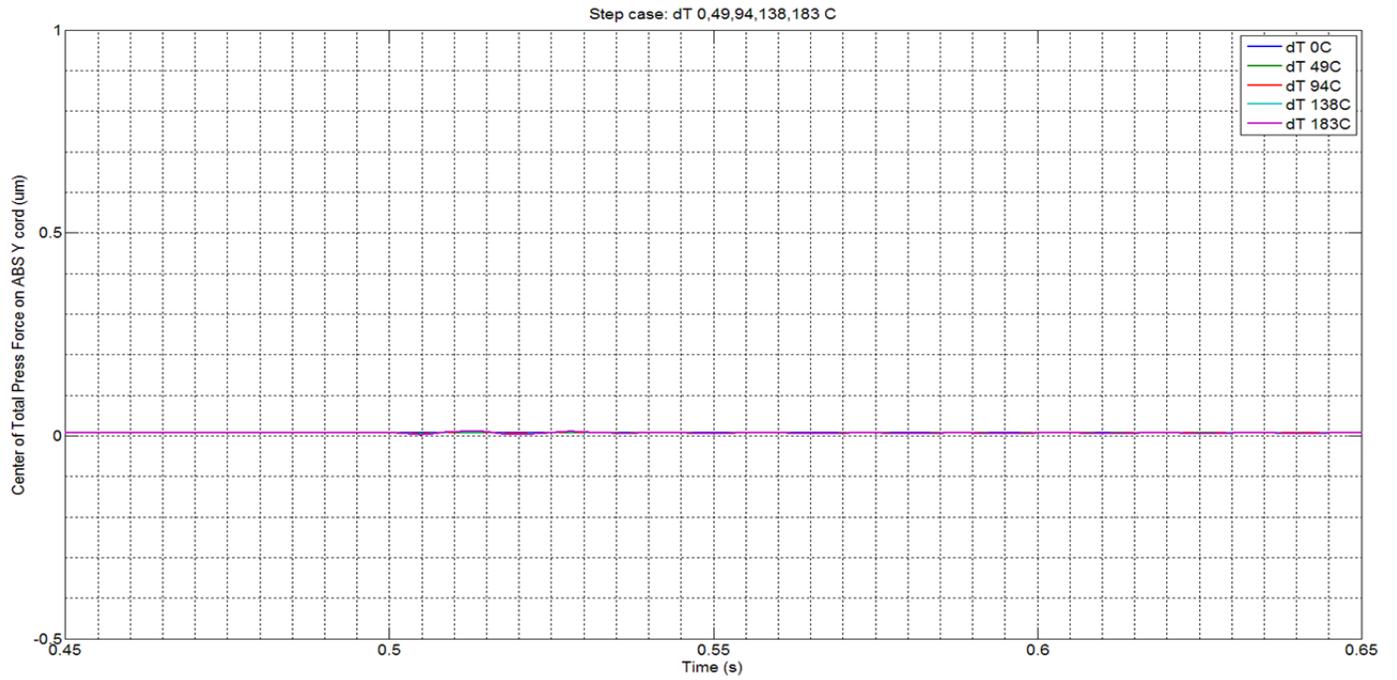


Figure 15. Center of total pressure force on ABS y coordinates versus time

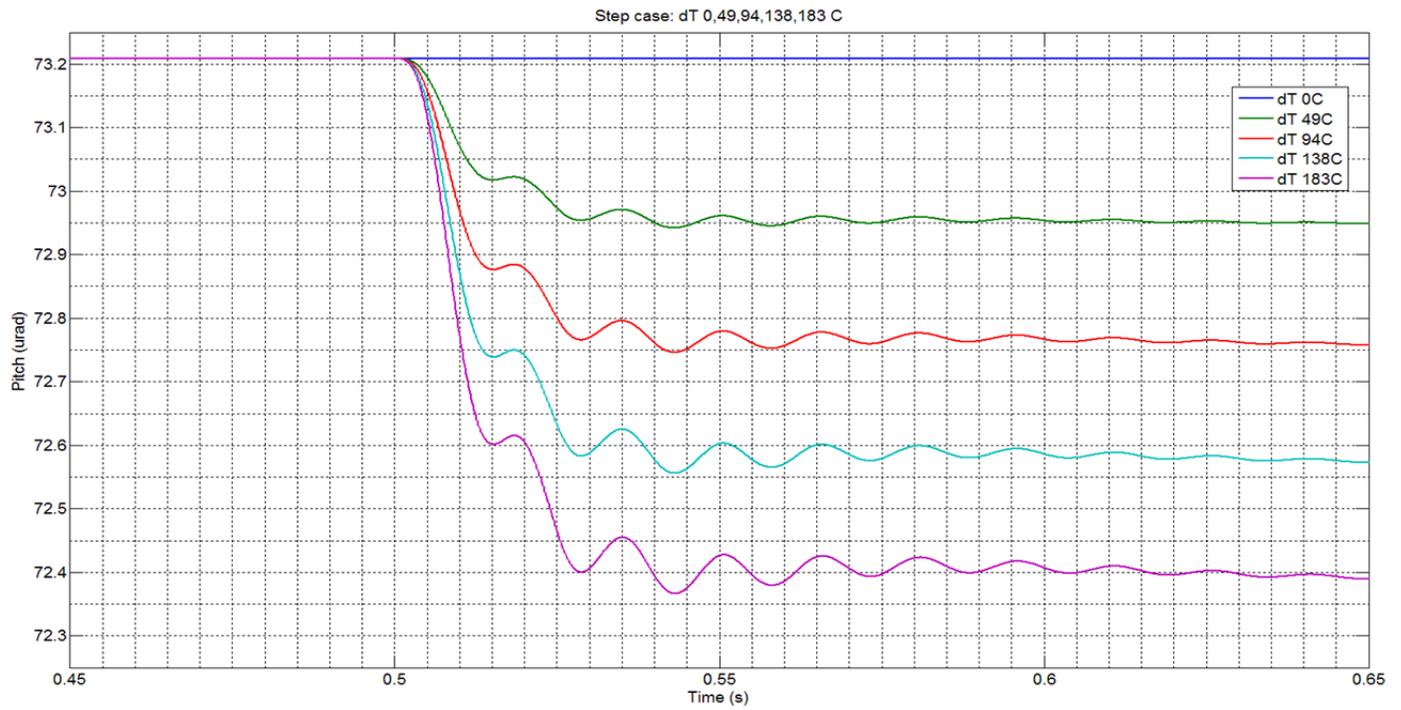


Figure 16. Pitch versus time

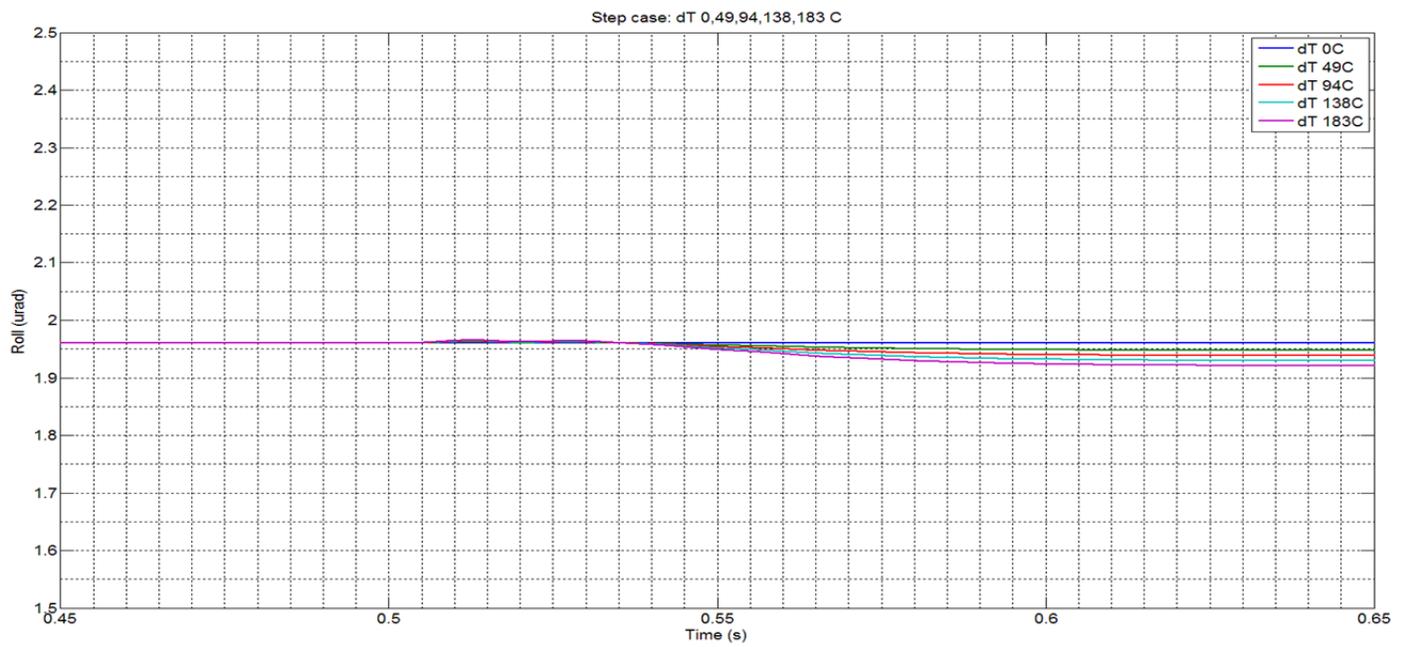


Figure 17. Roll versus time

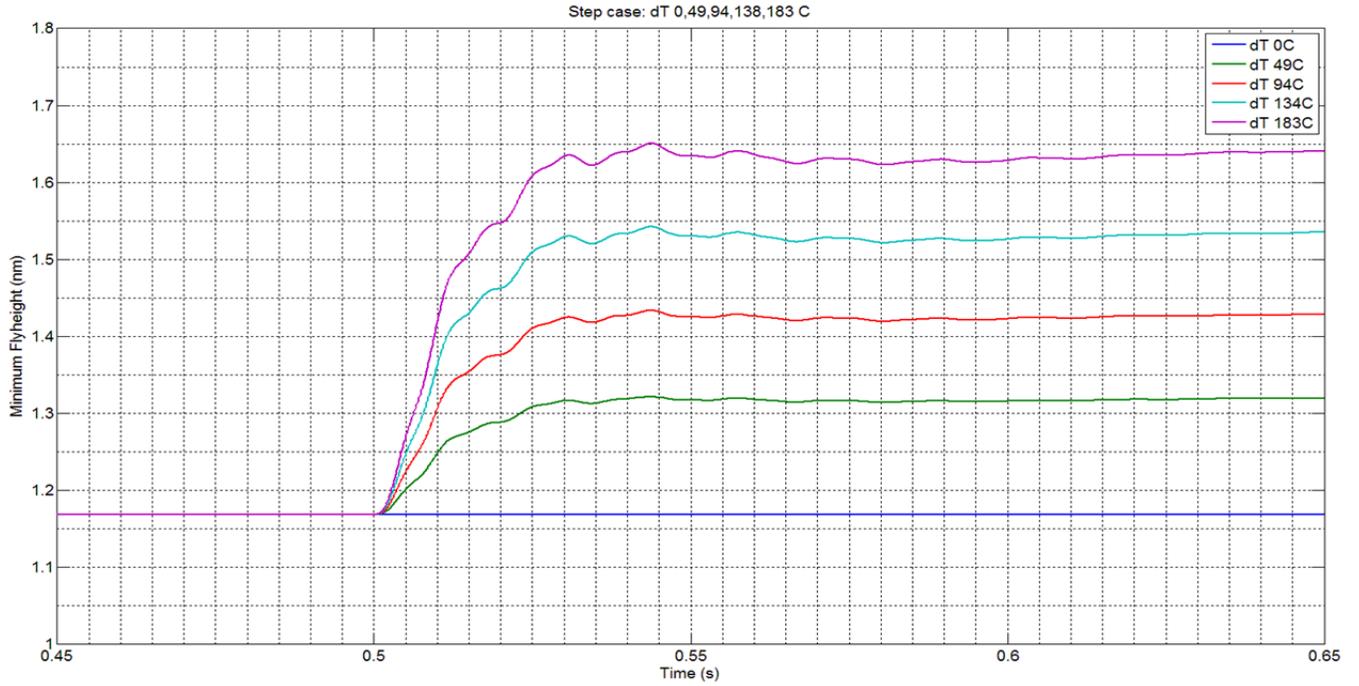


Figure 18. Minimum FH versus time

Pulse Case:

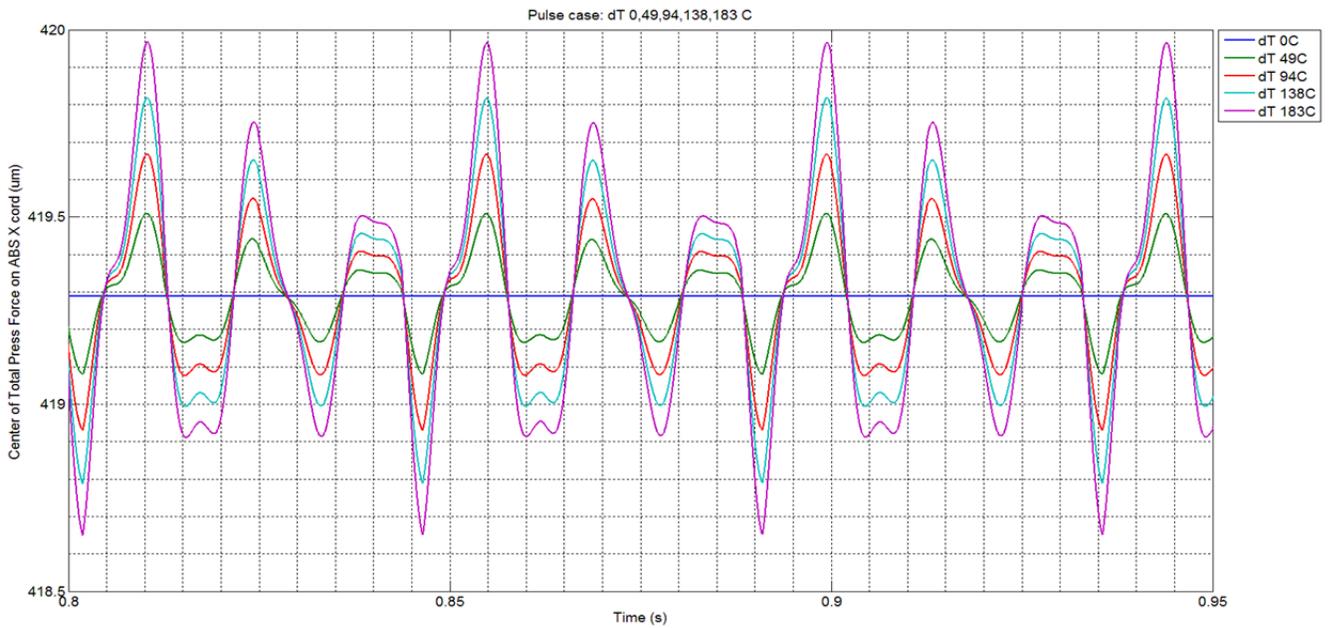


Figure 19. Center of total pressure force on ABS x coordinates versus time

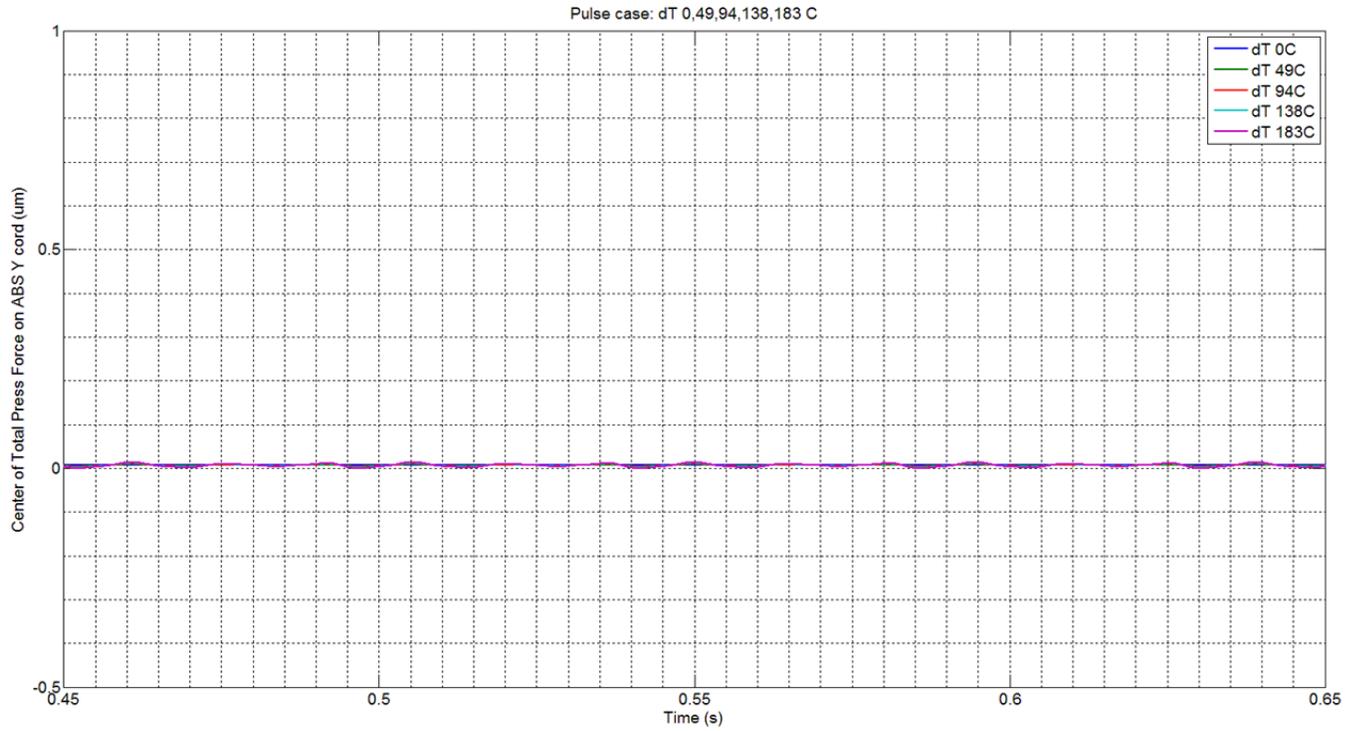


Figure 20. Center of total pressure force on ABS y coordinates versus time

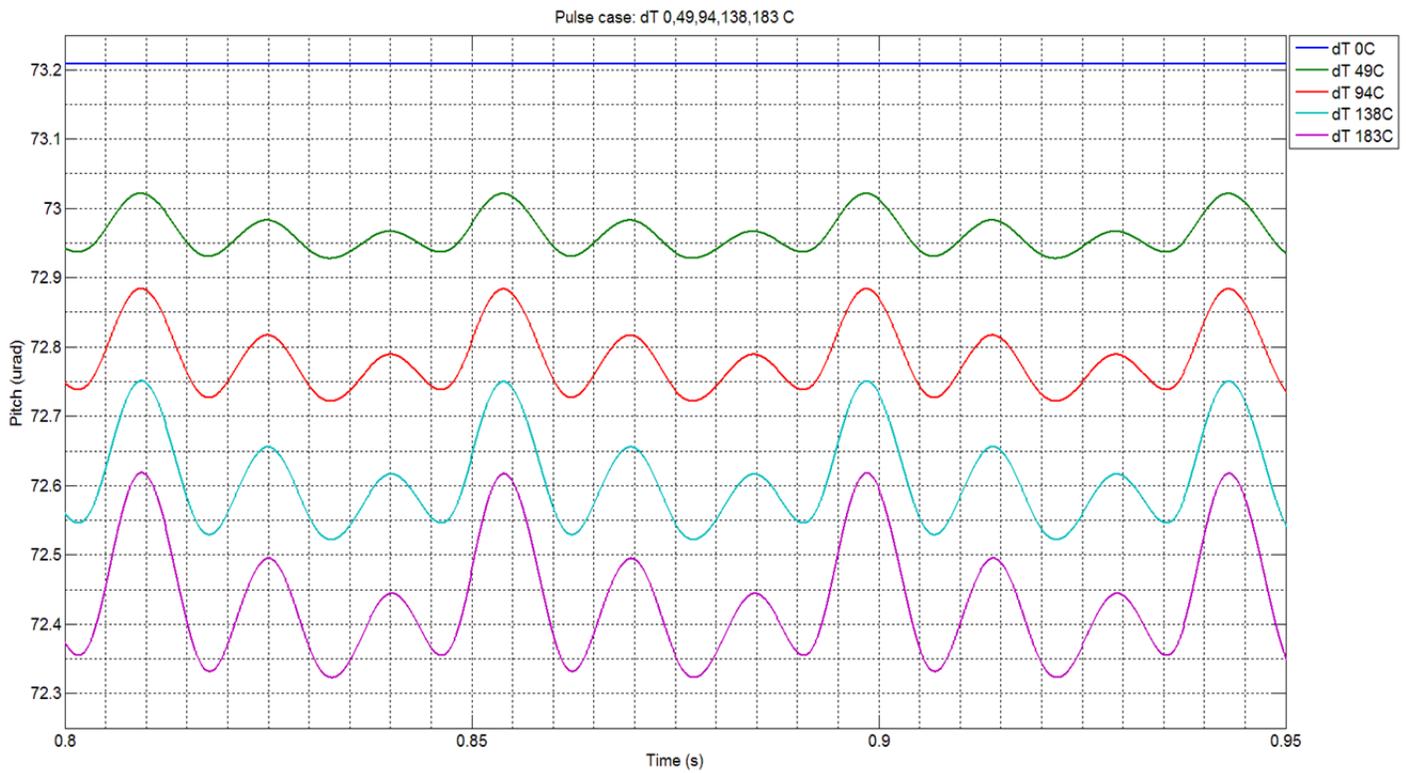


Figure 21. Pitch versus time

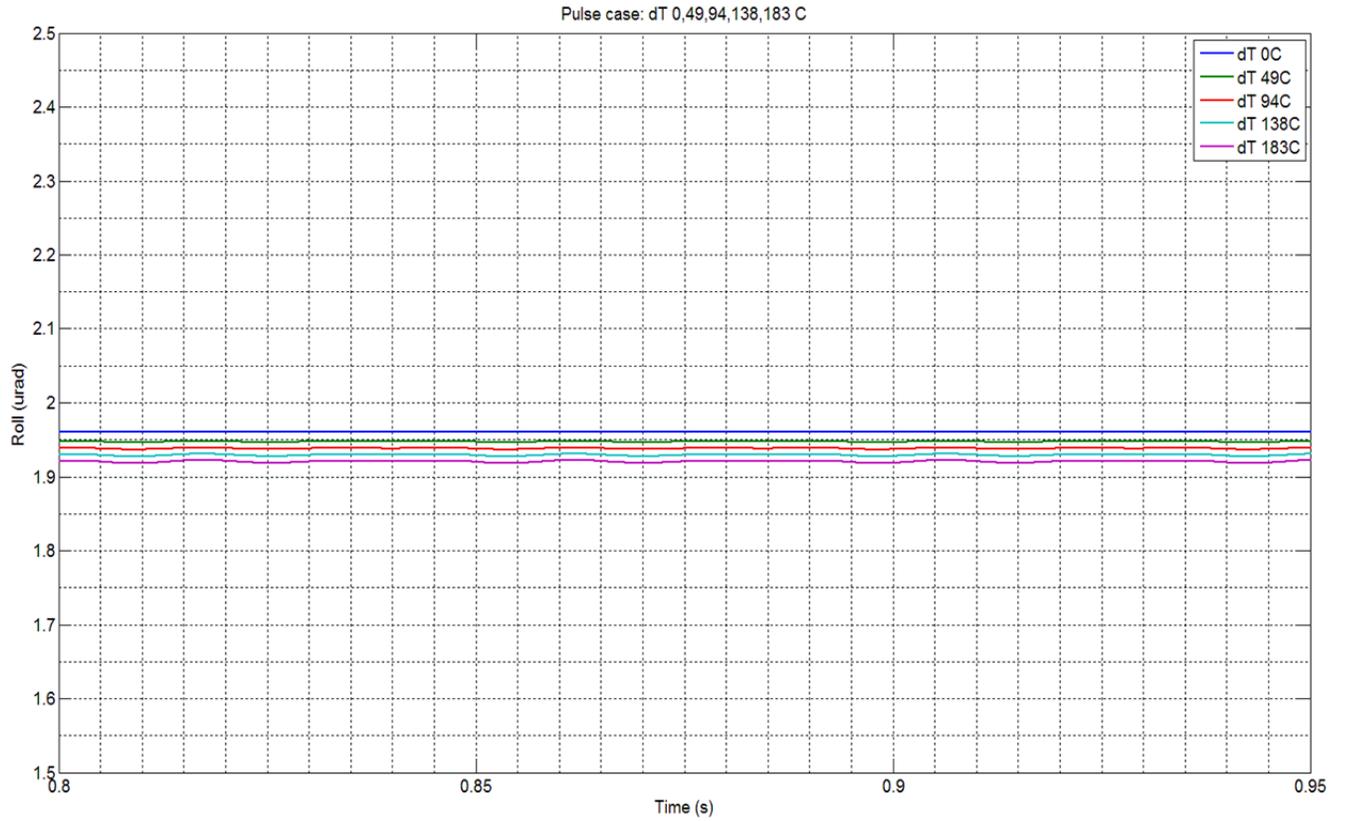


Figure 22. Roll versus time

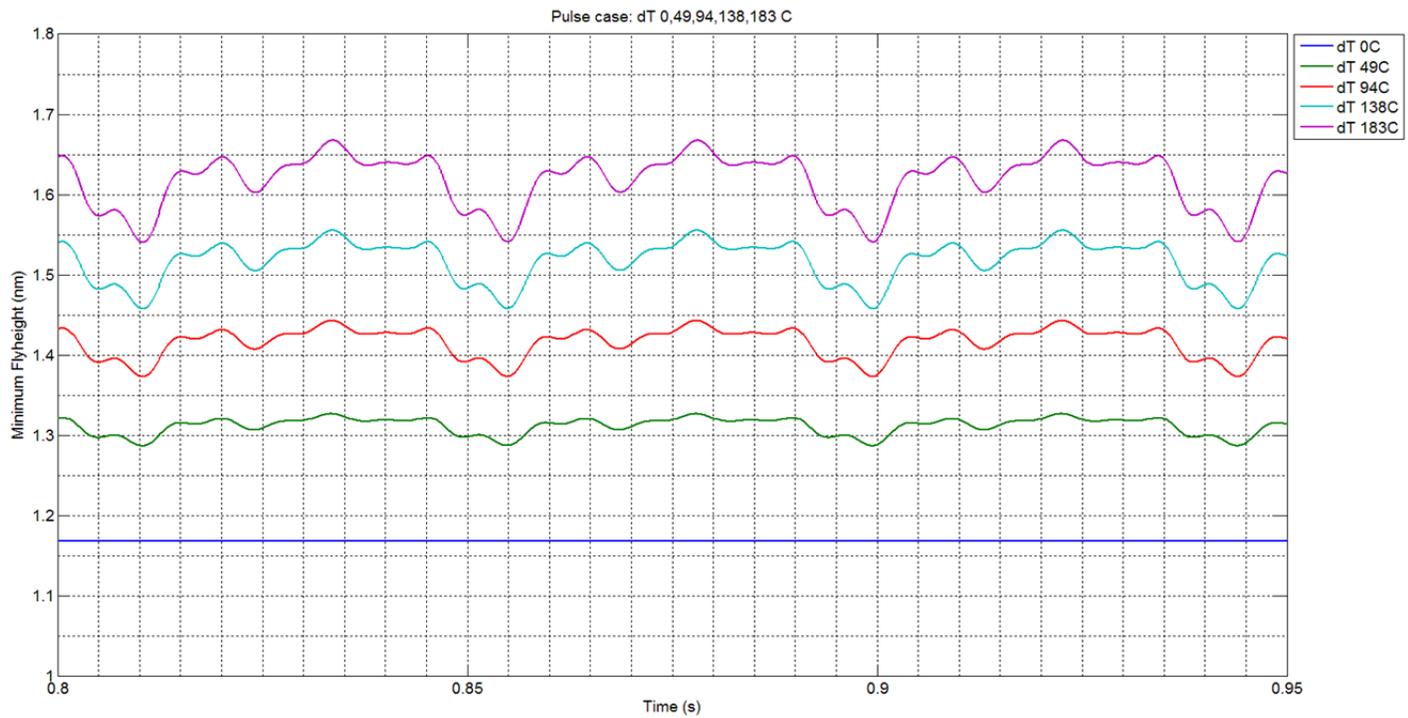


Figure 23. Minimum FH versus time

10. References

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