Method #5: Segment compensation

Video: Method #5 (Segment compensation)

This method begins with the nanobranch structure that has been specified for a “continuous” mode of FEBID exposure. This method describes a remeshing procedure for the nanobranch that acts to correct for the sub–linear deviation of the linear segment spanning vertices 1-2.

Action #1: Press “Remesh” (figure 1a).

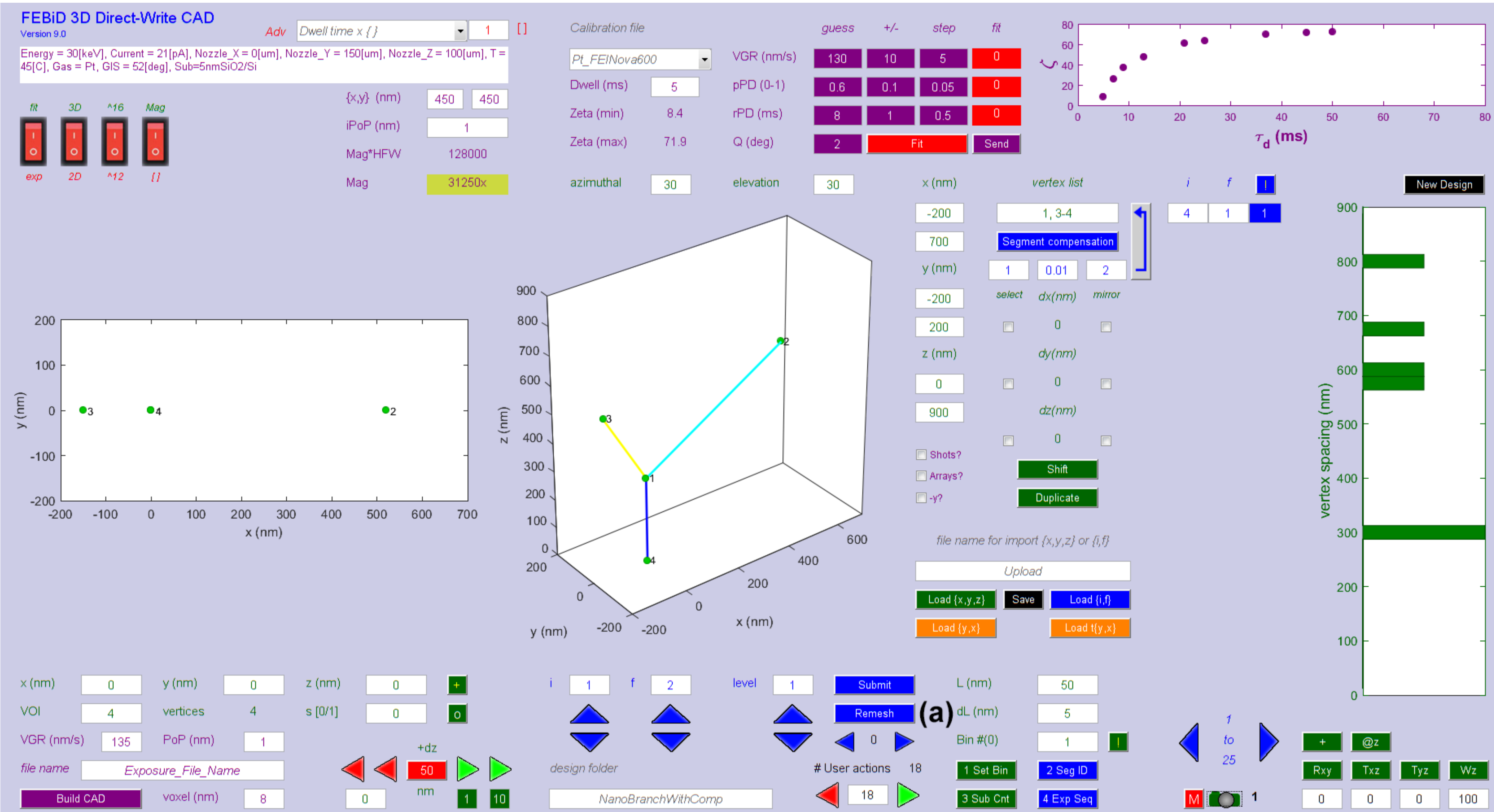

Figure 1

The “Remesh” function converts each element into two new elements of equal length (figure 2a).

A “segment sequence” or “pillar sequence” is created in response to the “Remesh” operation.

The exposure level sequence is updated preserving the order of exposure already defined by the original segment, i.e., the number of exposure levels has doubled but the sequence of segment has not changed. Experiments have been conducted to confirm that the CAD designs shown in both figure 1 and figure 2 yield the same nanostructure after FEBID. The numeral “1” which appears directly underneath the “Remesh” press button indicates that 1 remeshing operation has been executed (figure 2b).

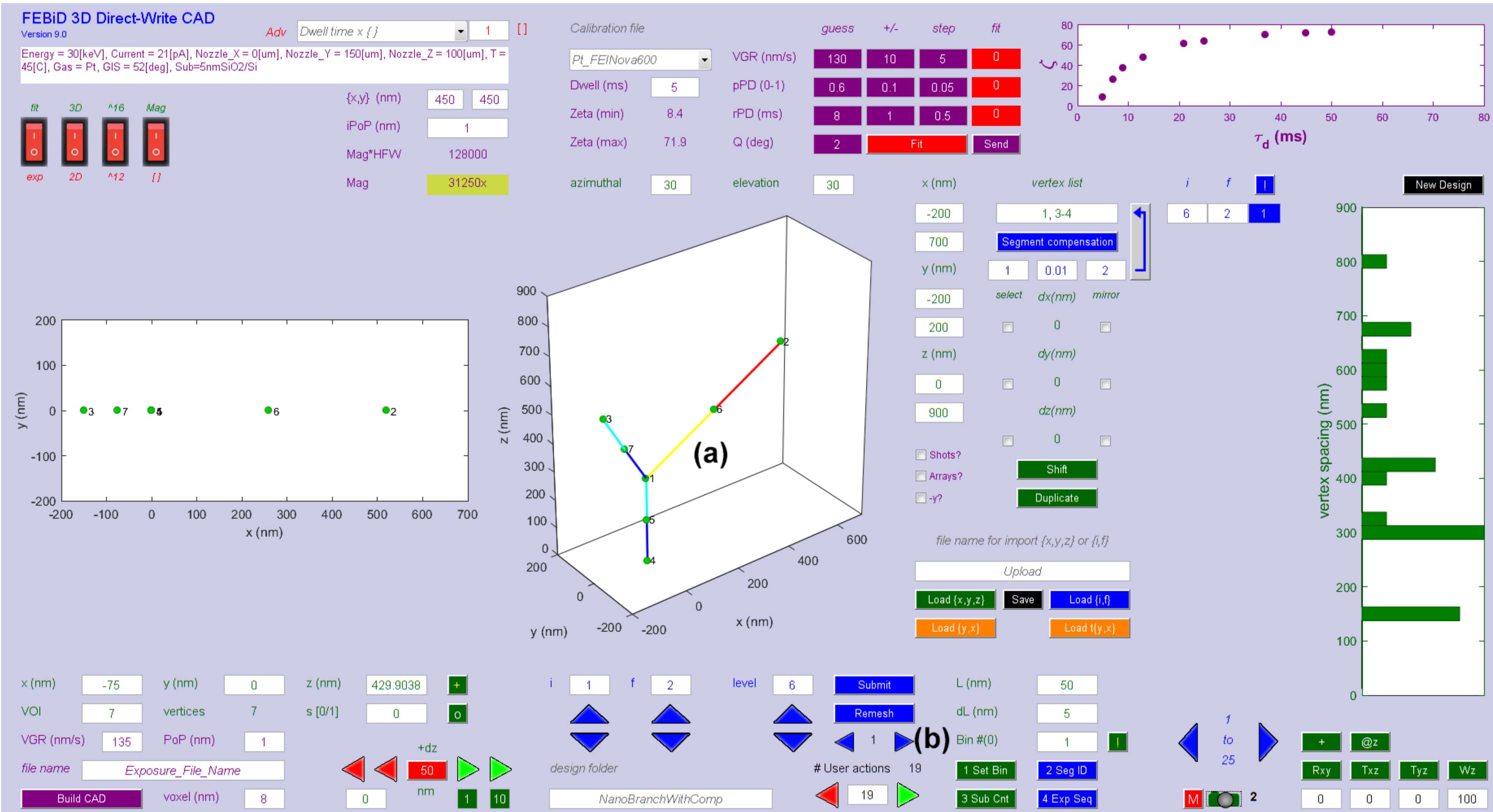

Figure 2

Action #2: Press the "Remesh" press button (figure 3a).

Action #1 is repeated and the nanobranch is again remeshed (figure 3b). The number of total remesh operations is updated to a value of 2 (figure 3c).

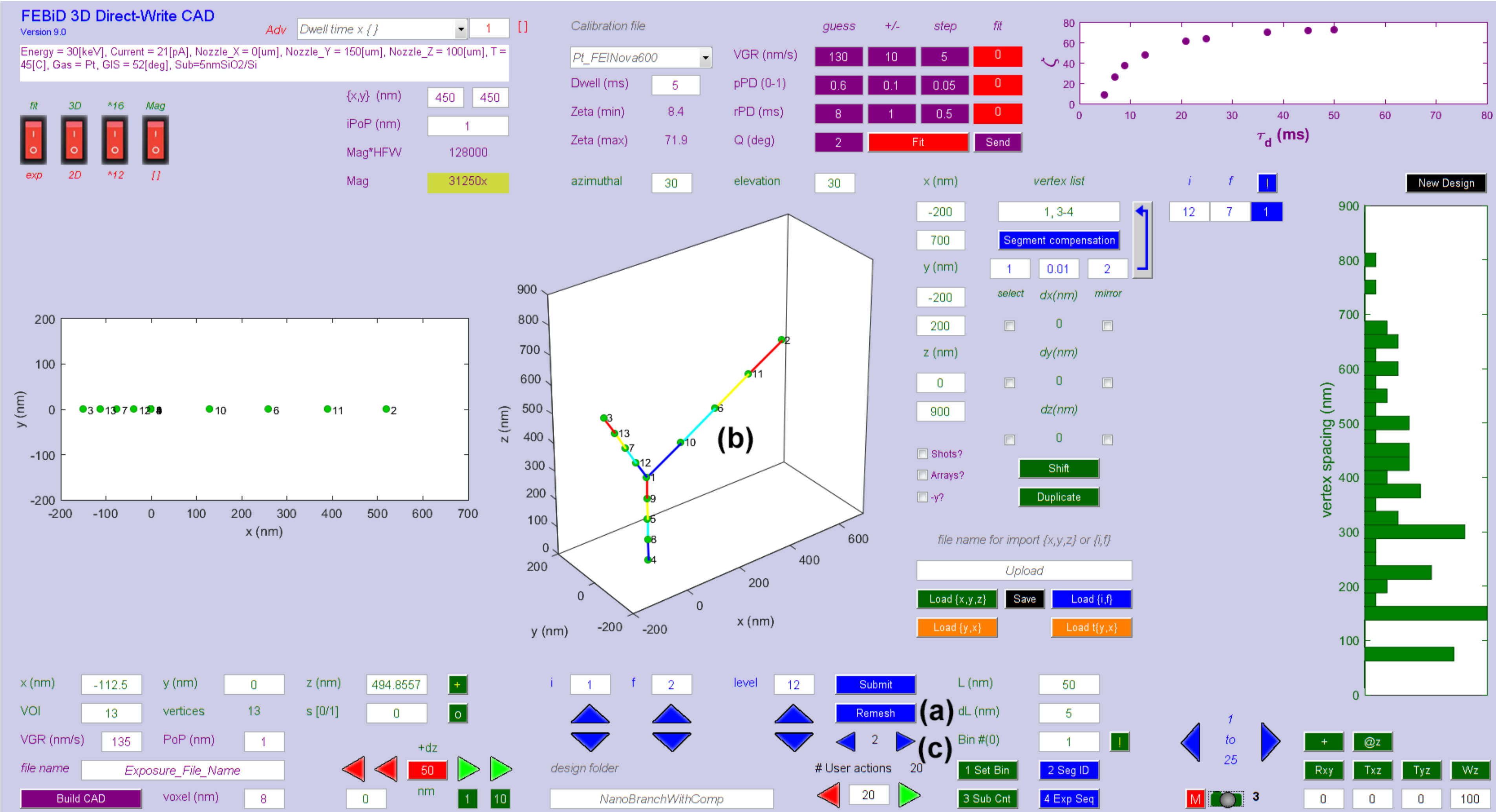

Figure 3

Action #3: Press the reverse action arrow button (figure 4a), twice.

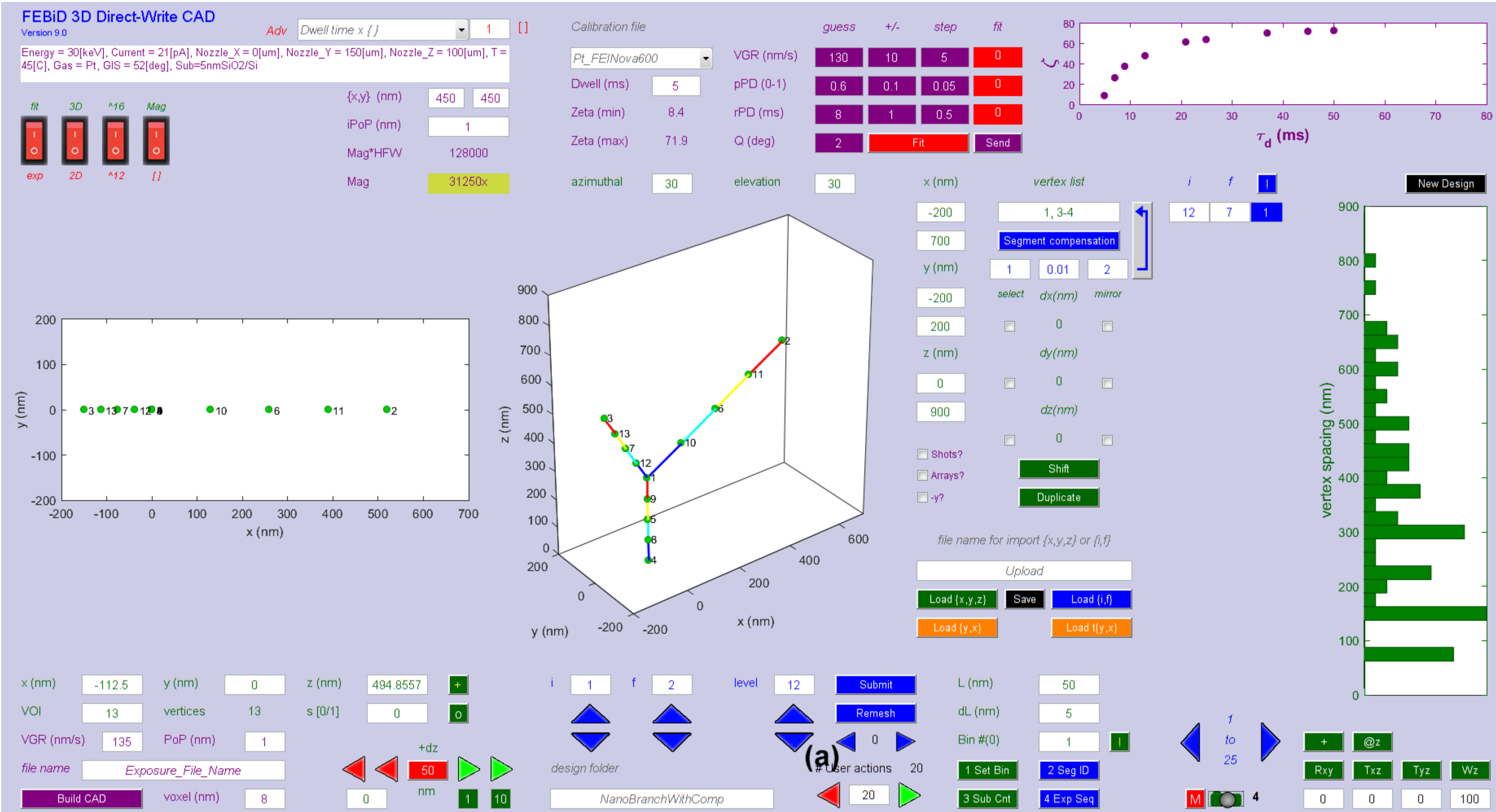

Figure 4

The remesh state updates in response to the action to “0” showing the complete distribution of currently defined vertices and segments.

Action #4: Press the forward action arrow button (figure 5a) once. The remesh state value increases to 1.

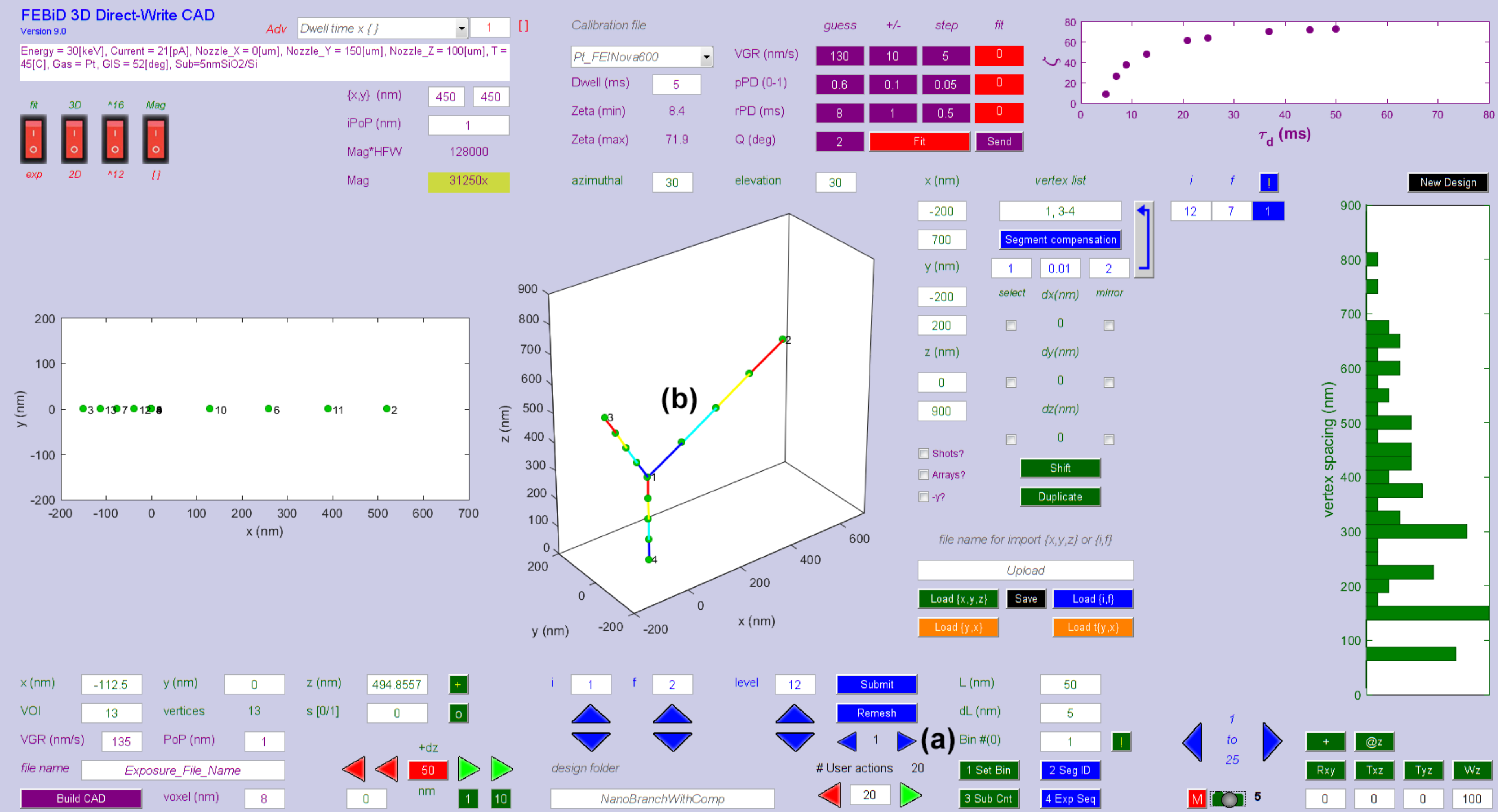

Figure 5

This action restricts vertex text labelling in the 3D plot to vertices specified *before the first remesh operation was executed*. This reduces visual clutter in the 3D plot and makes it easier to identify the initial and final vertices where a proximity correction may need to be applied. In this method, the segment spanning vertices 1-2 will need proximity correction because the segment angle in relatively low (30^o) while the segment is also relatively long (600 nm).

Action #5: Press the forward action arrow button (figure 6a) again. The remesh state increases to a value of 2.

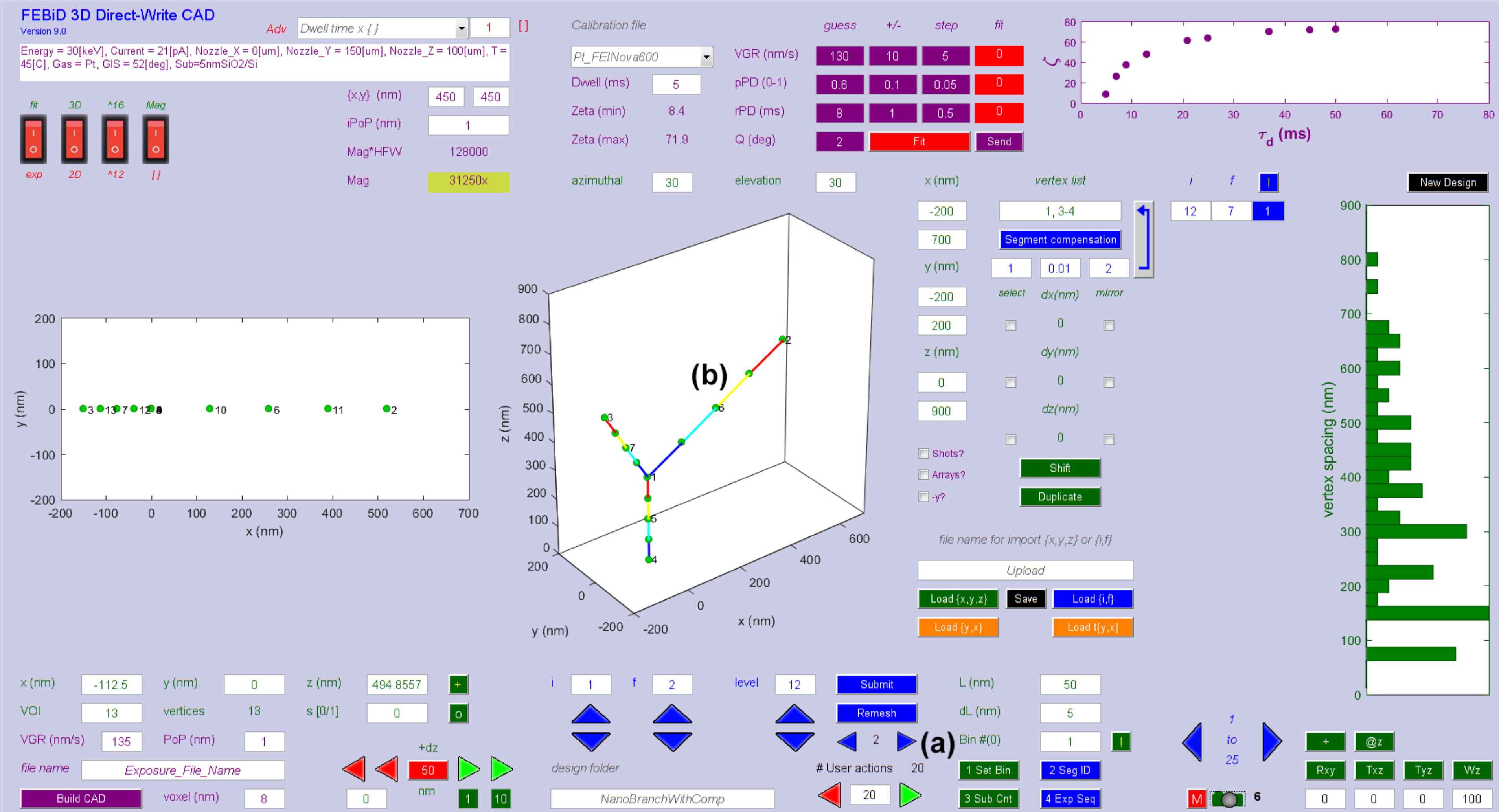

Figure 6

This action restricts vertex text labelling in the 3D plot to vertices specified *before the second remesh operation was executed*.

Action #6: Press the reverse action arrow button (figure 7a) twice. As a result, all vertices of the current design are labelled in the 3D plot.

Action #7: Enter a value of "1" in the text input box located below the "Segment Compensation" push button (figure 7b). This is the vertex index representing the initial position of the segment sequence for which proximity correction should be applied.

Action #8: Enter a value of "2" in the text input box located below the "Segment Compensation" push button (figure 7b). This is the vertex index representing the final position of the segment sequence for which proximity correction should be applied.

Action #9: Enter a value of "0.014" in the segment angle compensation text input box (figure 7b). The units for this parameter are [degrees per nanometer, or [°/nm].

The segment sequence spanning vertices 1-2 exhibits sub–linear bending during FEBID. This deviates from the intended linear segment called for in CAD. Compensation for this bending is achieved by imposing a super–linear bending in the design. The variable segment angle is calculated using the following procedure.

The desired segment angle is first computed from the initial and final vertex indices supplied in Actions #7 and #8;

$$\zeta_o = 30^o$$

A new segment angle is then calculated for each vertex which falls on the line spanning vertices 1 and 2 according to;

$$\zeta(x') = \zeta_o(x' = 0) + \frac{d\zeta}{dx'}x'$$

The equation applies to the segment frame of reference, or (x',z). The z–position of each vertex along the segment is increased by;

$$z(x') = z_0 + x' \cdot tan\big(\zeta(x')\big)$$

where z_o is the position of the vertex prior to the correction.

Action #10: Press the arrow push button (figure 7c). The vertices spanning the line between vertices 1 and 2 are automatically identified and displayed in the "vertex list" text input box (figure 7d). Alternatively, these values can also be entered manually.

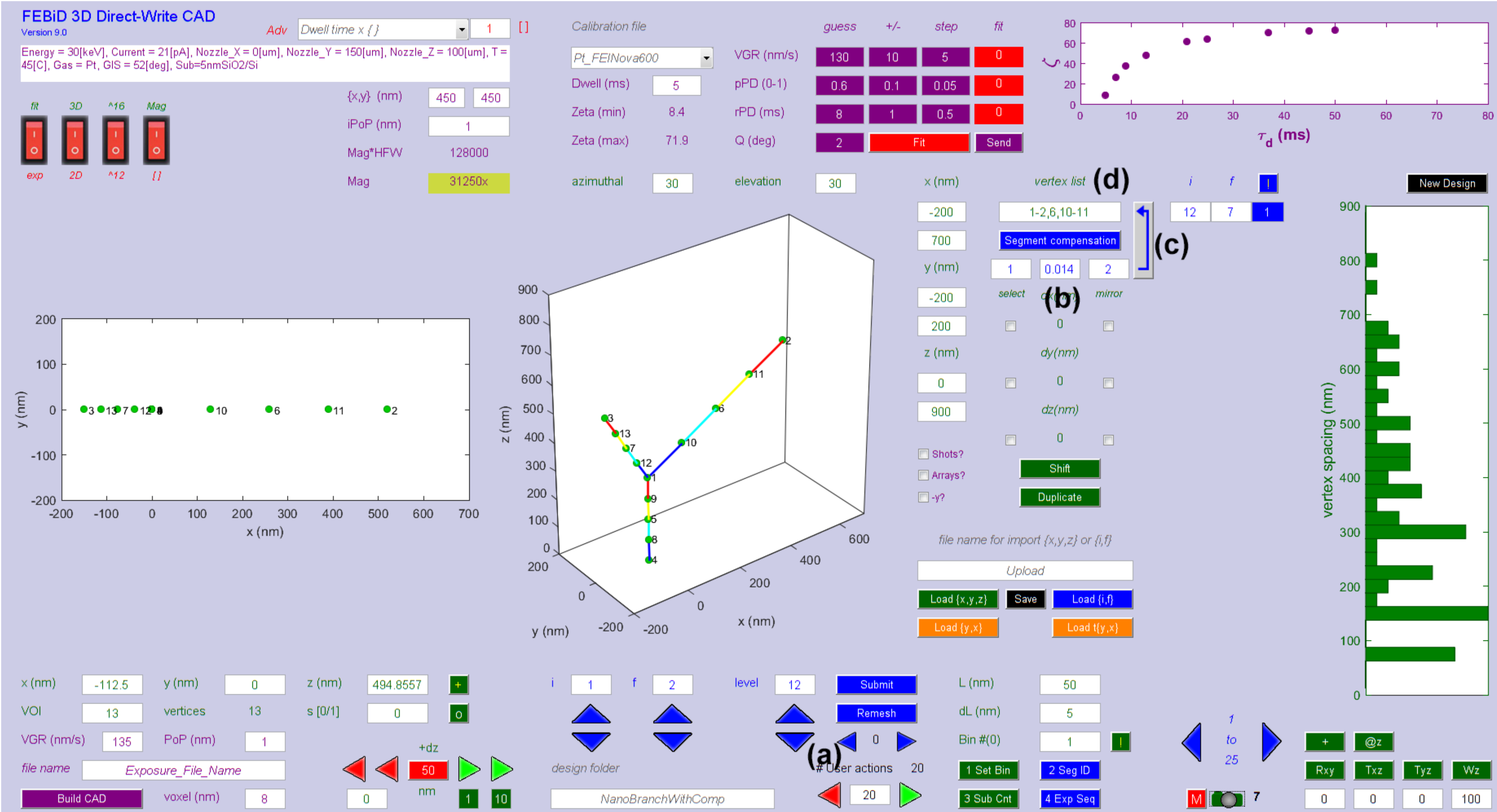
FEBiD 3D Direct-Write CAD
Version 9.0
Energy = 30[keV], Current = 21[pA], Nozzle_X = 0[um], Nozzle_Y = 150[um], Nozzle_Z = 100[um], T = 45[C], Gas = Pt, GIS = 52[deg], Sub=5nmSiO2/Si
Calibration file
Pt_FEINova600
vertex list (d)
1-2,6,10-11
Segment compensation
(c)
(b)
(a)
Build CAD
Exposure_File_Name
NanoBranchWithComp
New Design
vertex spacing (nm)
x (nm)
y (nm)
z (nm)
τ_d (ms)

Figure 7

Action #11: Press the "Segment compensation" button (figure 8a). A new set of vertices are calculated and segments are reassigned.

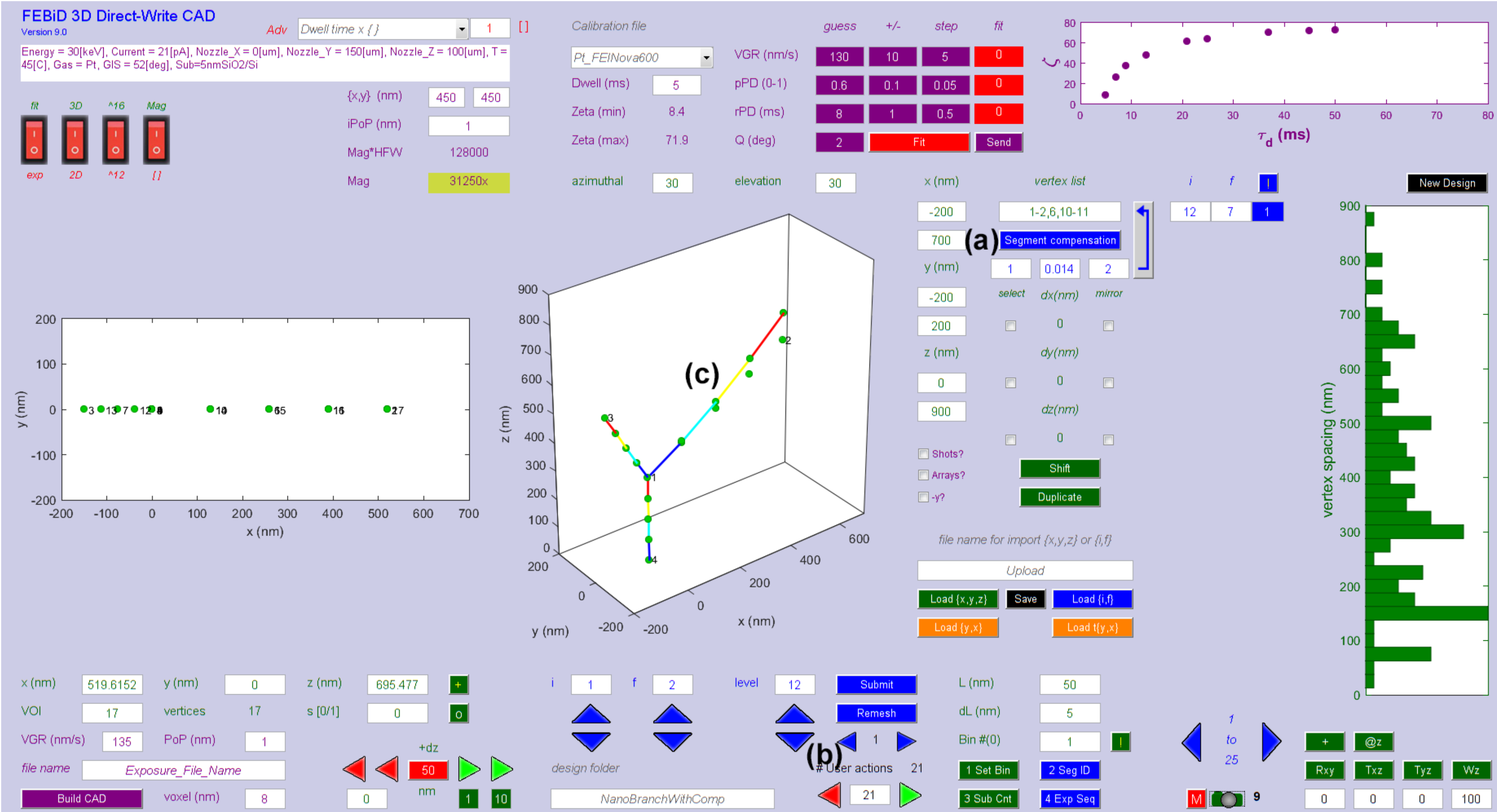

Figure 8

The remesh state was set back to the initial design (figure 8b) to show that the proximity correction has been applied along (x') spanning the original vertices 1 and 2 (figure 8c). For clarity of exposure sequence, figure 9 shows each exposure level exposure mode for this example.

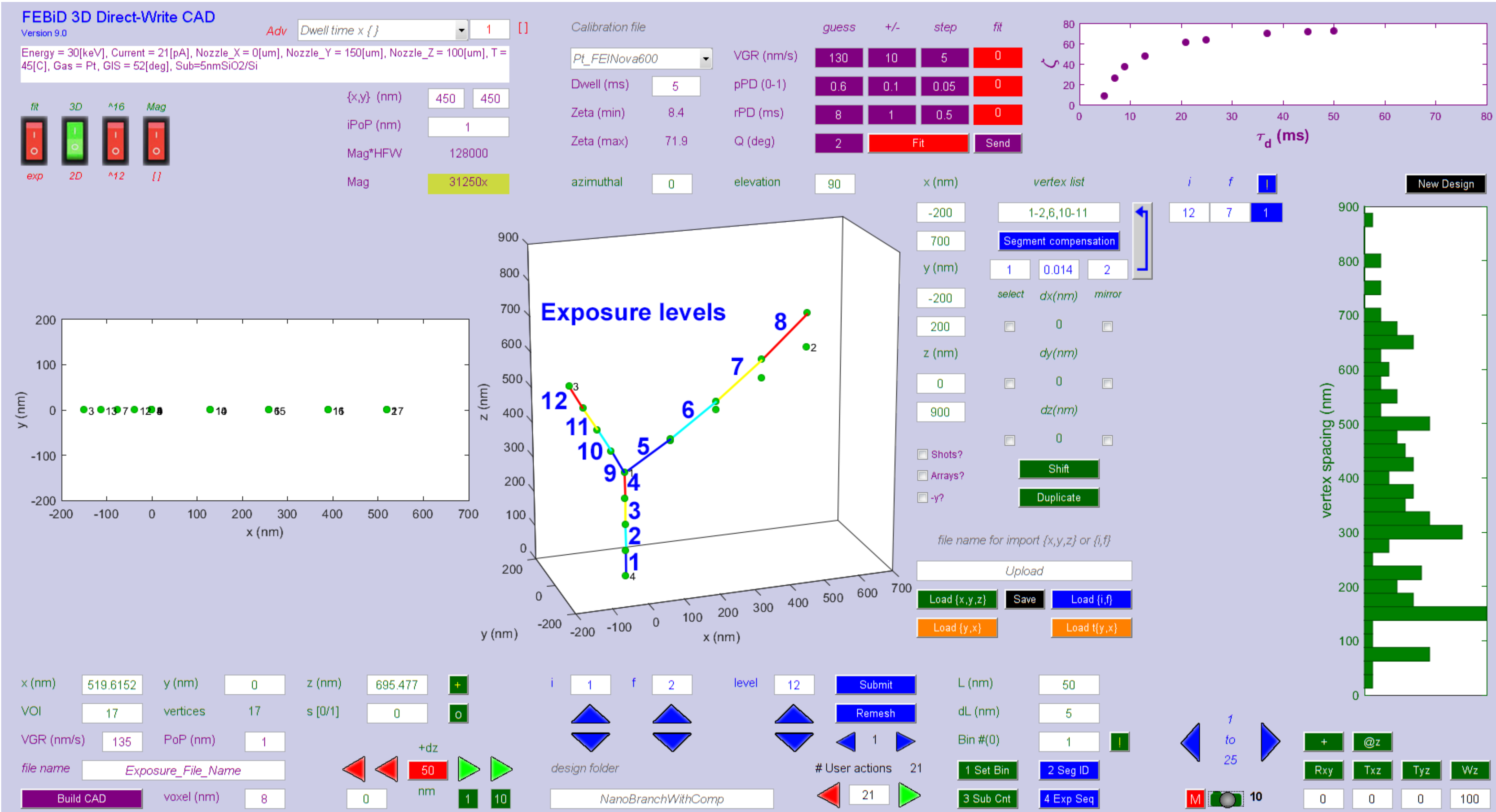
FEBiD 3D Direct-Write CAD
Version 9.0
Energy = 30[keV], Current = 21[pA], Nozzle_X = 0[um], Nozzle_Y = 150[um], Nozzle_Z = 100[um], T = 45[C], Gas = Pt, GIS = 52[deg], Sub=5nmSiO2/Si
Calibration file
Pt_FEINova600
Exposure levels
vertex list
Segment compensation
New Design
vertex spacing (nm)
file name for import {x,y,z} or {i,f}
Build CAD
Exposure_File_Name
NanoBranchWithComp
Submit
Remesh
Shift
Duplicate
Fit
Send
Save
design folder
User actions 21

Figure 9

Action #12: Press the “o” push button (figure 10a).

This action hides any vertices that are not used in segment definition. This can help clarify the image of a complex 3D object image during design (figure 10b).