ME237

Mechanics of Microsystems project

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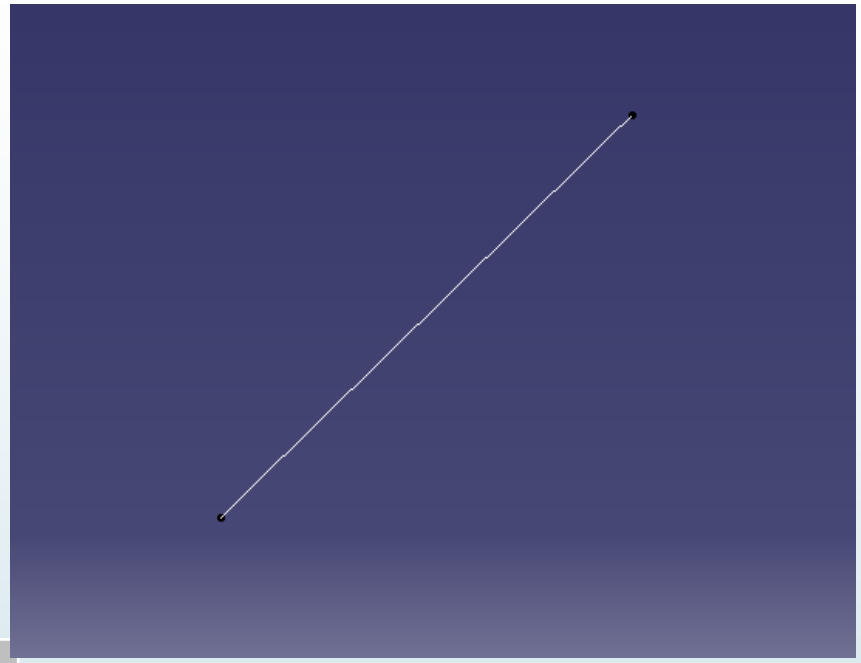
Instructor: Prof. G.K.Ananthasuresh

Objective

- Modify FEM 3D beam code, catering for the accurate direction cosines.
- Static pull in voltage for 1 DOF system by root locus method (Animation).
- Static pull in voltage for 2 DOF system by root locus method (Animation).
- Equilibrium solution of 2 DOF systems by energy landscape.
- Dynamic pull in voltage for 1 DOF system (Animation).

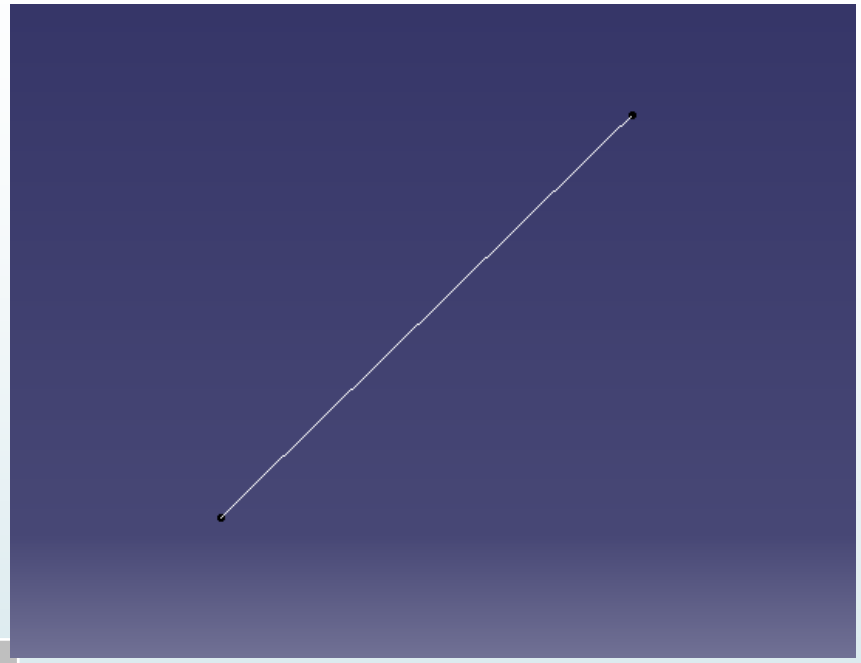
FEM 3D Beam



Node.dat

Node no	X	Y	Z
1	0	0	1
2	1	2	3

FEM 3D Beam



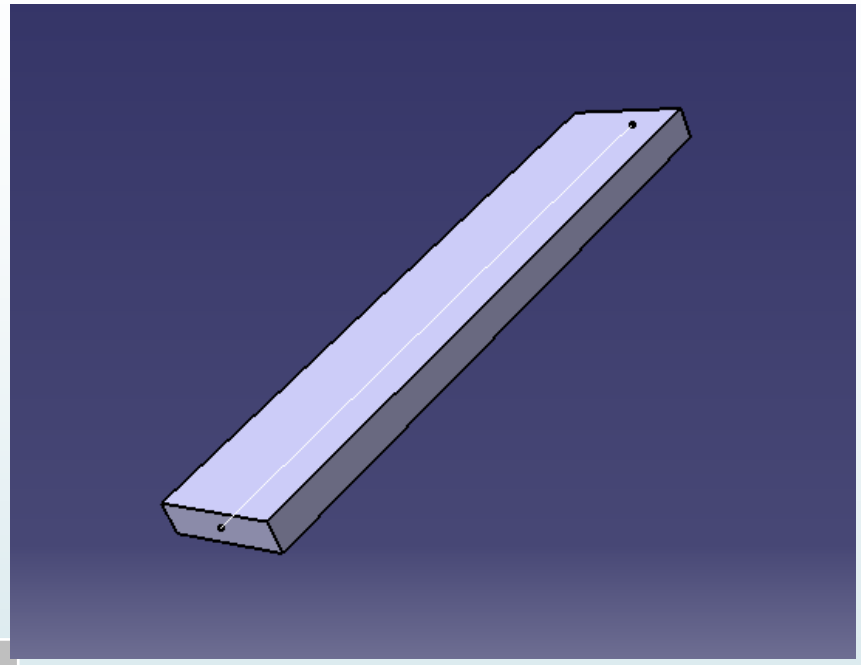
Node.dat

Node no	X	Y	Z
1	0	0	1
2	1	2	3

elem.dat

Sl no	Node1	Node2	Depth	width	E	lx	ly	Lz
1	1	2	40	10	155e3	0	0	1
…	…	…	…	…	…	…	…	…

FEM 3D Beam



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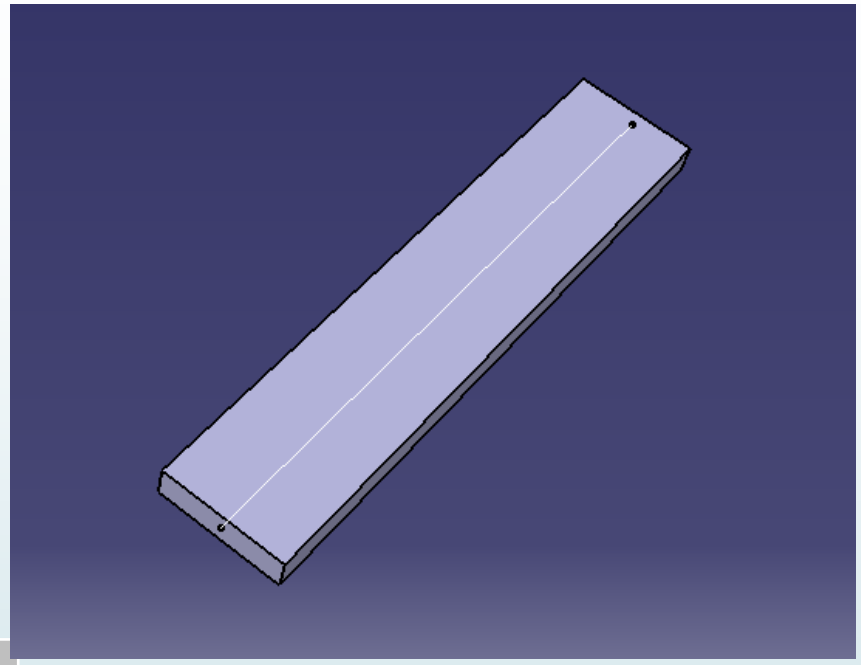
…	…	…	…	…	…	…	…	…

FEM 3D Beam



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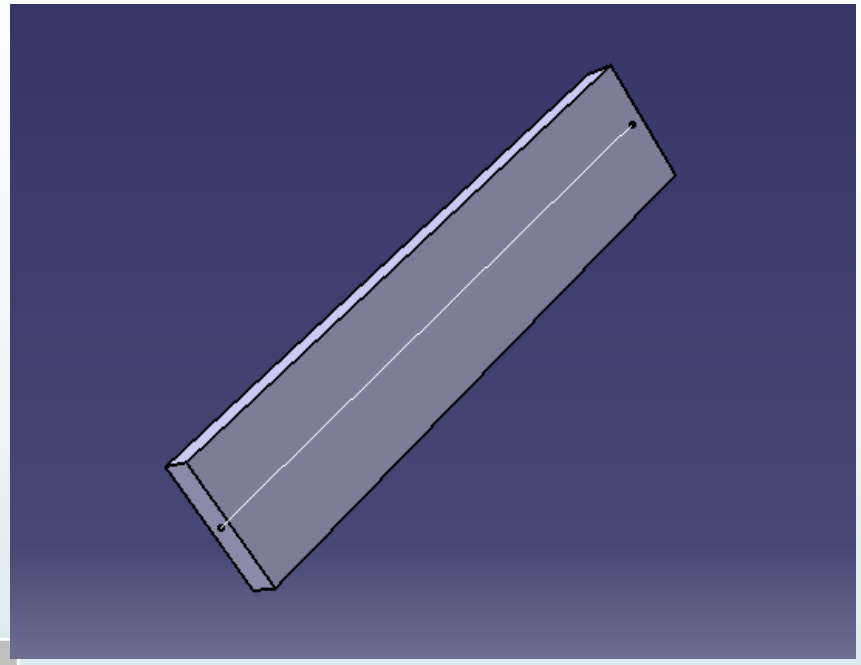
FEM 3D Beam



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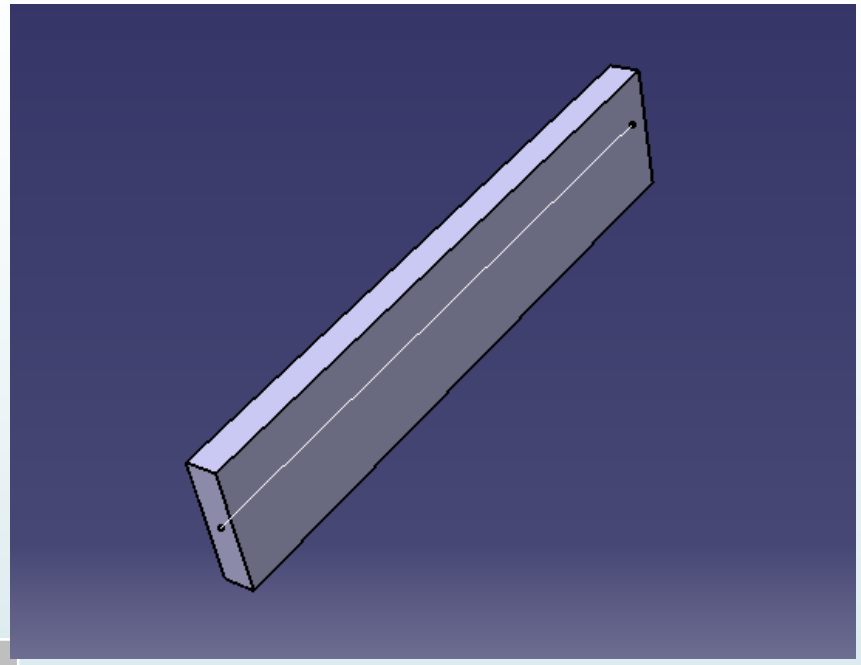

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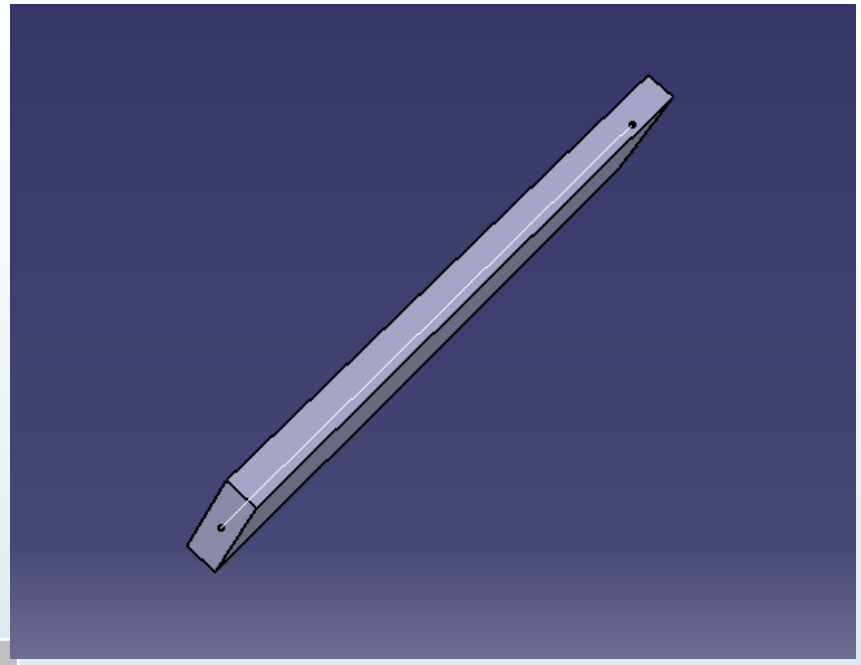
1	1	2	40	10	155e3	0	0	1
…	…	…	…	…	…	…	…	…

FEM 3D Beam



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elem.dat

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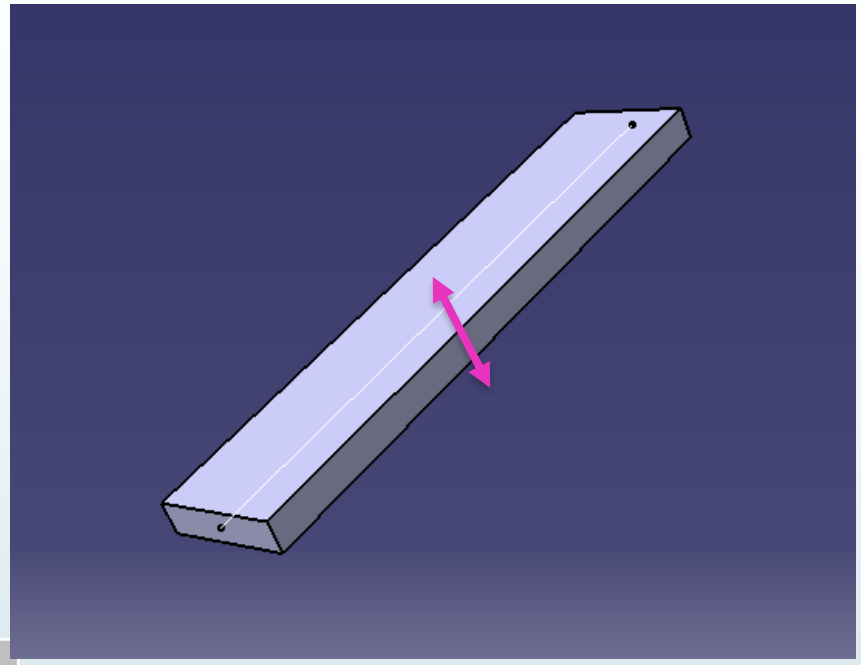
1	1	2	40	10	155e3	0	0	1
…	…	…	…	…	…	…	…	…

FEM 3D Beam



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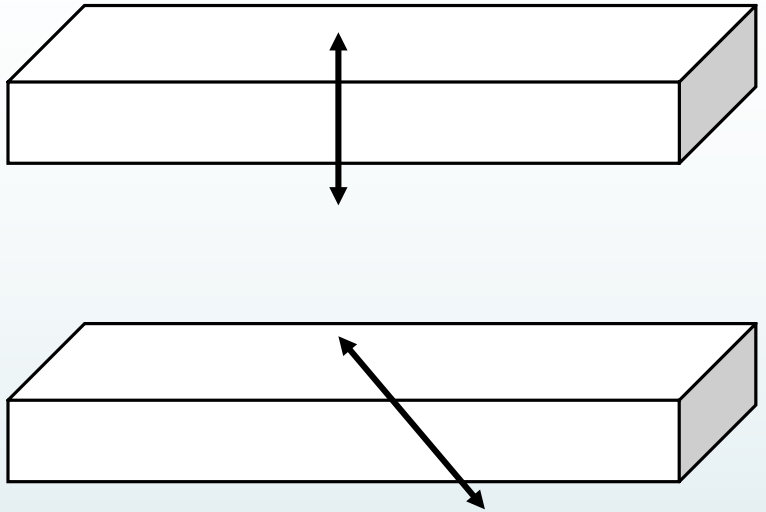
2	1	2	3

elem.dat

Sl no	Node1	Node2	Depth	width	E	lx	ly	Lz
1	1	2	40	10	155e3	0	0	1
…	…	…	…	…	…	…	…	…

FEM 3D Beam



Node.dat

Node no	X	Y	Z
1	0	0	0
2	1	0	0

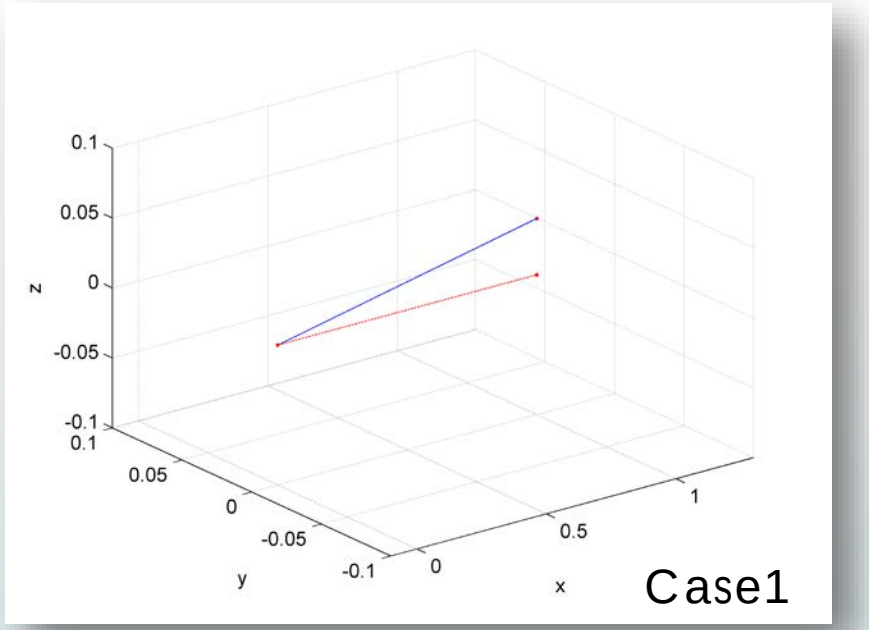
elem.dat (Case1)

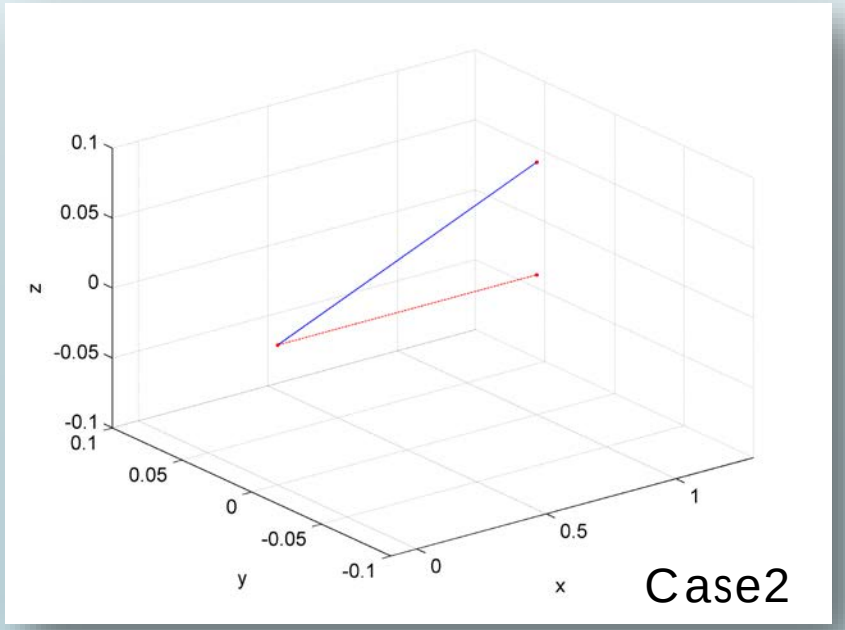
Sl no	Node1	Node2	Depth	width	E	Ix	Iy	Lz
1	1	2	10	40	155	0	0	1

elem.dat (Case2)

Sl no	Node1	Node2	Depth	width	E	Ix	Iy	Lz
1	1	2	10	40	155	1	0	1

Disp	Case1	Case2
U1x	0	0
U1y	0	0
U1z	0	0
θ1x	0	0
θ1y	0	0
θ1z	0	0
U2x	0	0
U2y	0	0
U2z	0.040323	0.080645
θ2x	0	0.085537
θ2y	-0.06048	-0.12097
θ2z	0	0





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Stack: Base

```matlab
    t(i,2) = ( ny(ncon(i,2))-ny(ncon(i,1)) );
    t(i,3) = ( nz(ncon(i,2))-nz(ncon(i,1)) );
    t(i,:) = t(i,:)./sqrt(sum(t(i,:).^2));
end

% Make n1 a unit vector
tol=1e-6;
ii=1; n1_new=0;
for i = 1:NELEM,
    n1(i,:) = n1(i,:) / sqrt( n1(i,1)^2 + n1(i,2)^2 + n1(i,3)^2 ); % n1 directional unit vector
    % Generate error message if t and n1 are not orthogonal
    pr=dot(elem(i,[7 8 9]),t(i,:));
    if (pr>tol)
       err1(ii,1)=i;
       err1(ii,[2,3,4])= elem(i,[7 8 9]);
       n1_new= elem(i,[7 8 9])- pr*t(i,:);
       err1(ii,[5,6,7])=n1_new;
       ii=ii+1;
    end
end

if(ii>1)
    disp('WARNING!!!');
    disp('Few of the direction cosines given in elem.dat file (column number 7,8,9)');
    disp('are not orthogonal to direction of beam element.');
    disp('element no, original direction cosines, and suggested direction cosines are given below');
    disp('The elem no, lx, ly, lz, l2x, l2y, l2z ');
    tt=num2str(err1);
    disp(tt);
end

n2 = cross(t,n1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

script | Ln 76 | Col

MATLAB 7.10.0 (R2010a)

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Current Folder: D:\IISc\Mechanics of microsystems ME237\Project\FEM3Dbeam

Shortcuts How to Add What's New

Current Folder

« FEM3Dbeam

Name

- 2.tif
- beam3.m
- dispbc.dat
- elem.dat
- fea3D.m
- forces.dat
- matcut.m
- New Microsoft Excel Worksheet.xlsx
- node.dat
- untitled.tif
- veccut.m

Details

Command Window

New to MATLAB? Watch this Video, see Demos, or read Getting Started.

```
WARNING!!!
Few of the direction cosines given in elem.dat file (column number 7,8,9)
are not orthogonal to direction of beam element.
element no, original direction cosines, and suggested direction cosines are given below
The elem no, lx, ly, lz, l2x, l2y, l2z
1   1   0   1   0   0   1
>>
```

Suggested direction cosines

Original direction cosines

Workspace

Stack:

Name	Value
node	[1,0,0,0;2,1,0
nx	[0;1]
ny	[0;0]
nz	[0;0]
pr	1
rho	0.1600
sortIndex	[1,2,3,4,5,6]
t	[1,0,0]
tmp	[-0.1000,1.3(
tol	1.0000e-06
tt	'1 1 0 1 0
u	<12x1 doub

Command History

```
disp('are not orthog
disp('element no, or
disp('elem no, lx, l
tt=num2str(err1);
disp(tt);
end
disp(\n)
disp('\n')
disp('/n')
disp('{/n}')
disp({/n})
clc
u
```

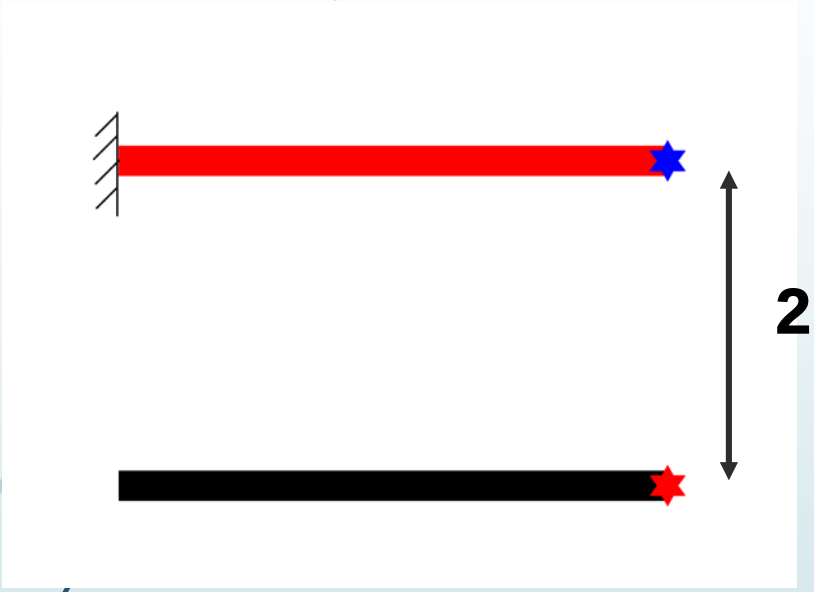
Start

FEM 3D Beam

MATLAB CODE

beam3.m

Static pull-in 1DOF



Methods

- Energy landscape
- Roots of equilibrium equation
- ....
- ....

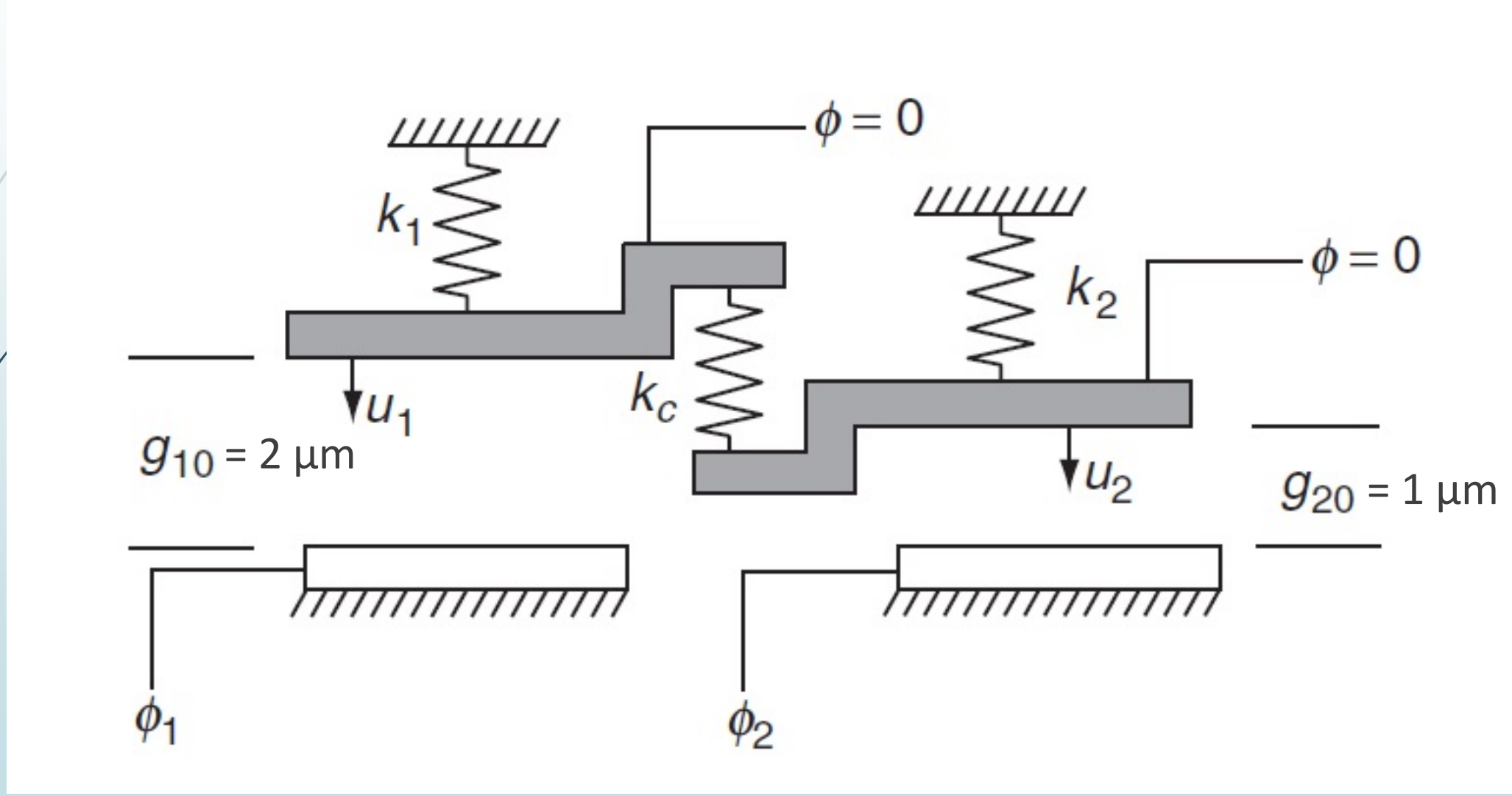
Cubic equilibrium equation → 3 root

Static pull-in 1DOF

MATLAB CODE

static_pullin.m

Static pull-in 2DOF



Static pull-in 2DOF

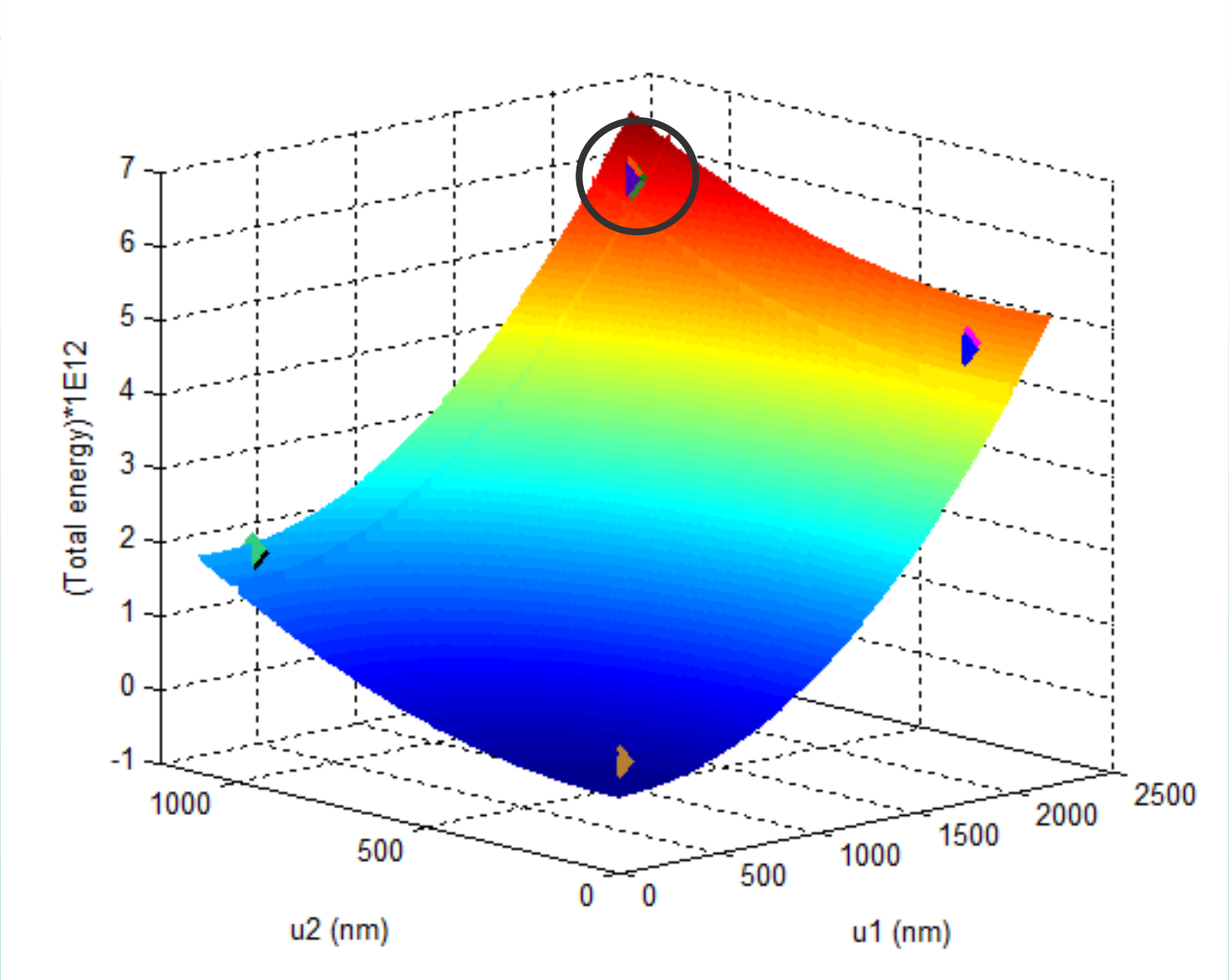
- Cubic in u1 and cubic in u2
- 9 pairs of solution for each V1 and V2

Static pull-in 2DOF using root-locus

MATLAB CODE

Q5_rootlocus.m

Sol^{n} of 2 DOF systems by energy landscape



Sol^{n} of 2 DOF systems by energy landscape

U1= 2e-06
U2= 1e-06

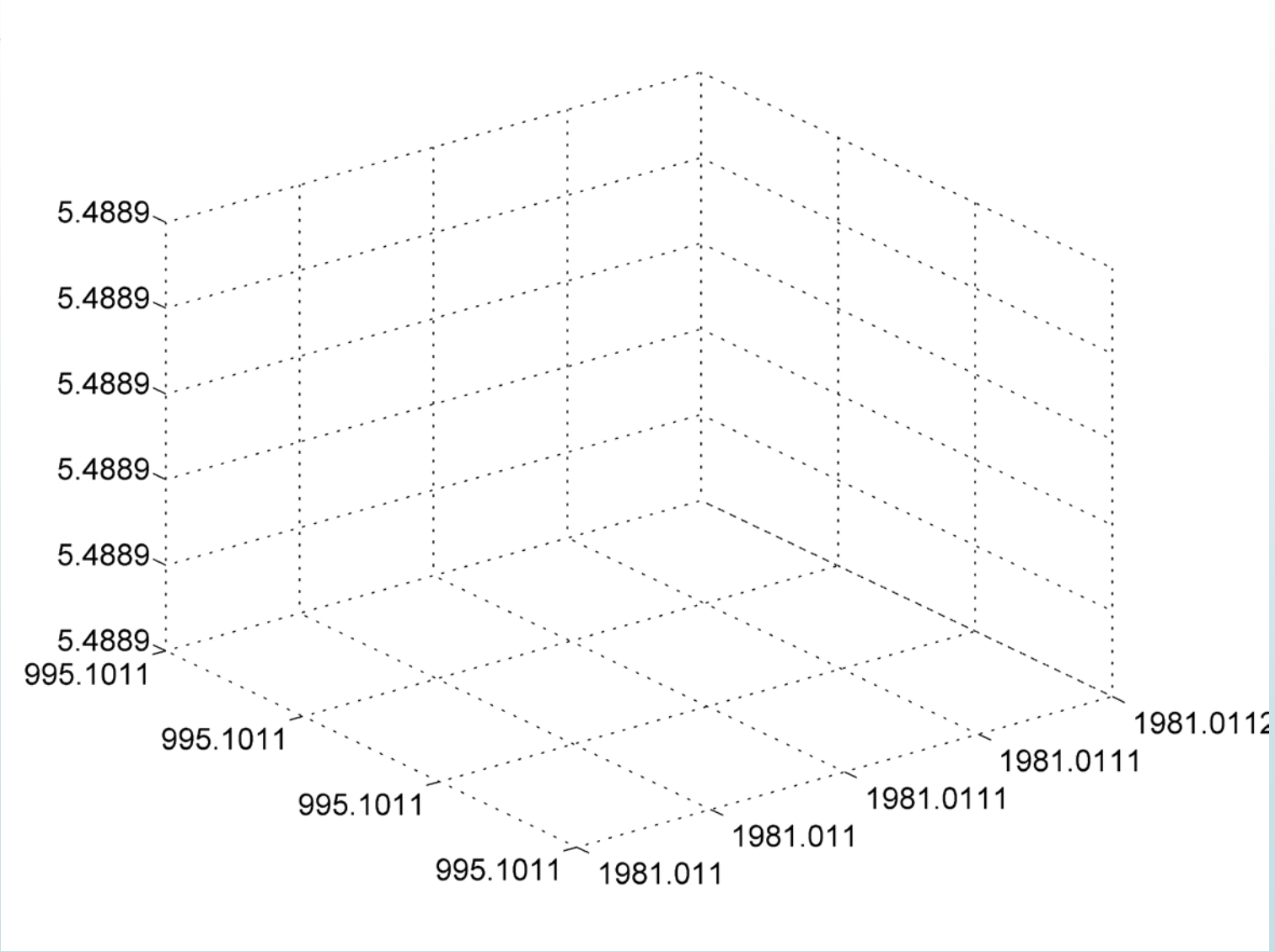
Energy landscape around the root??

X= 1.9e-6 : 1e-9 : 2.1e-6

Y= 0.9e-6 : 1e-9 : 1.1e-6

TE = F(x,y)

Sol^{n} of 2 DOF systems by energy landscape



Sol^{n} of 2 DOF systems by energy landscape

Energy variation wrt u1 and u2

U2 →

5.488e-6	5.488e-6	..	..	..	..
5.488e-6	5.488e-6	..	..	..	..
5.488e-6	5.488e-6	..	..	..	..
:	:				
:	:				
:	:				
:	:				
:	:				
:	:				

U1 →

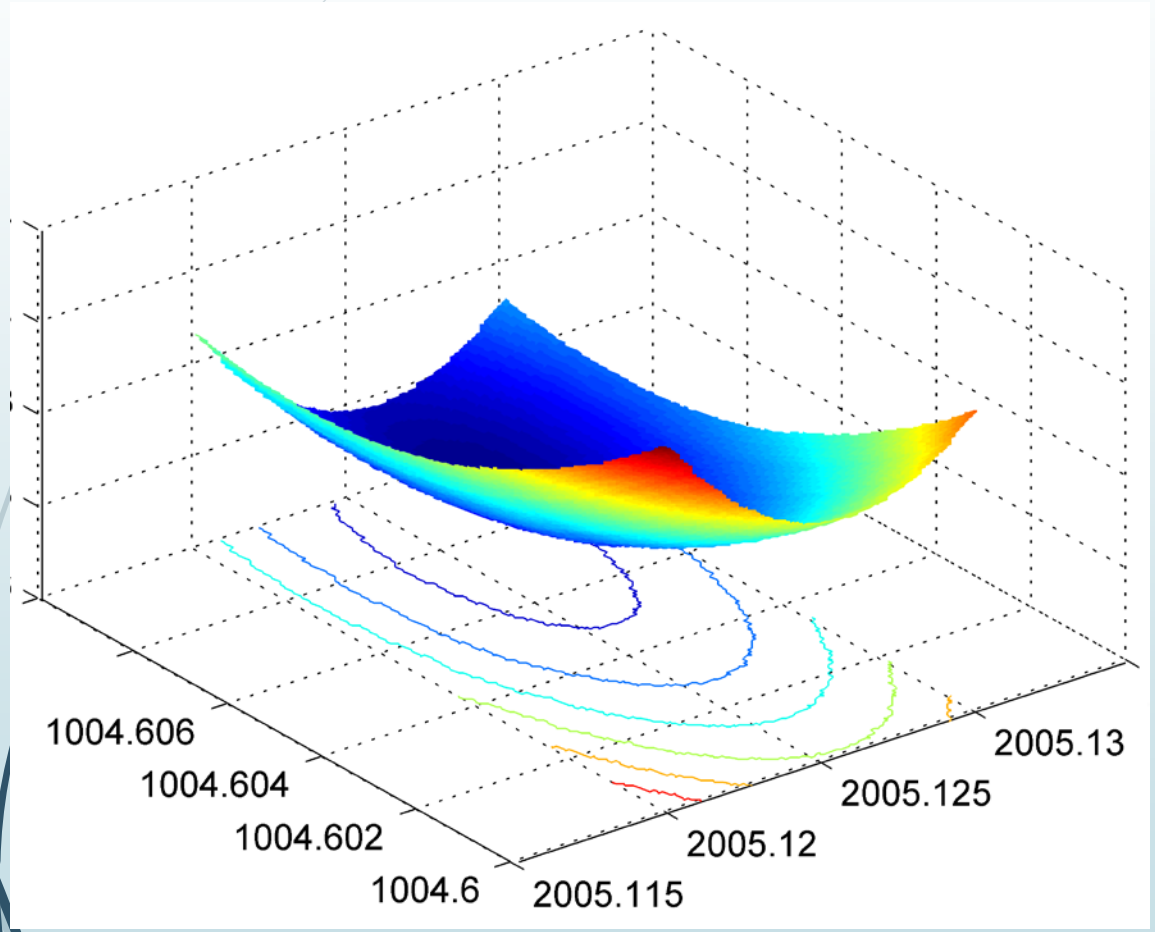
Sol^{n} of 2 DOF systems by energy landscape

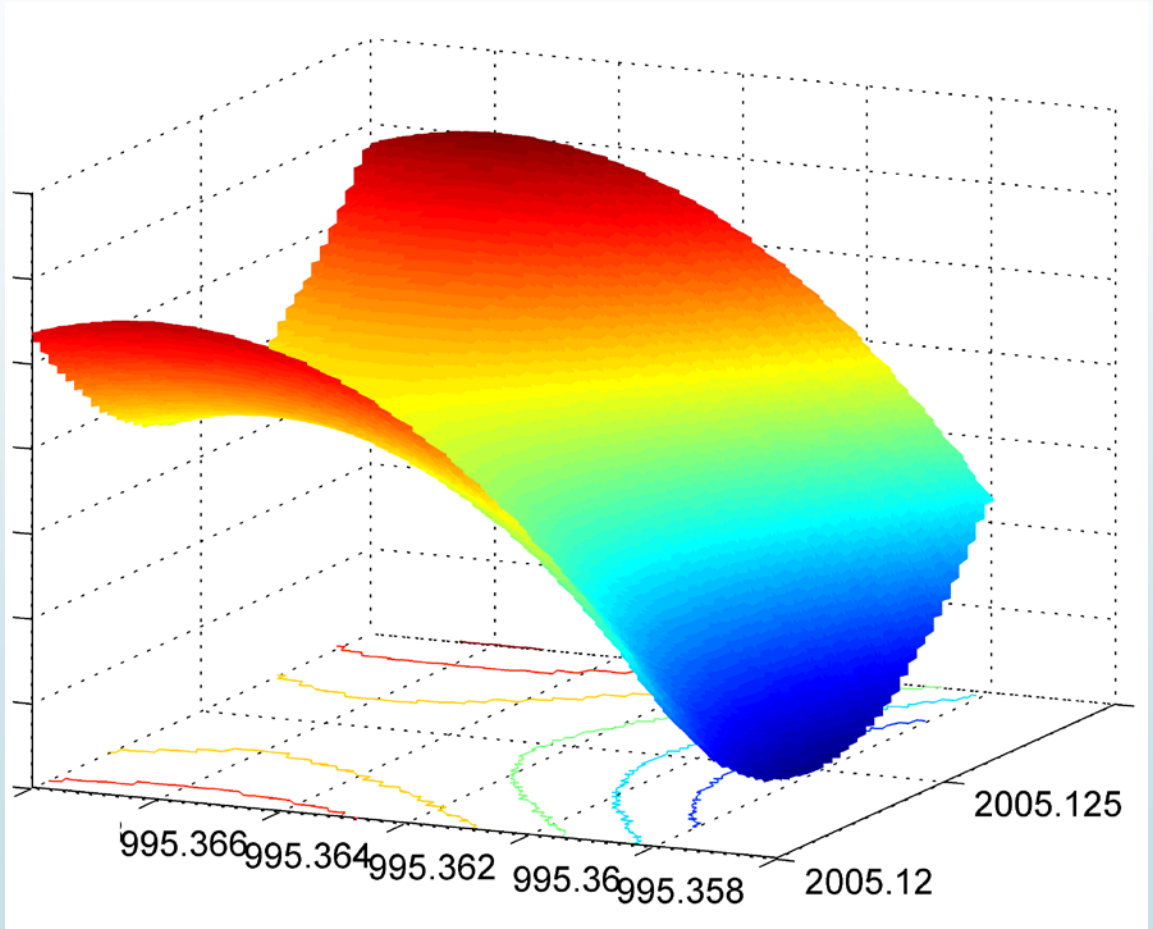
Max(Energy)= 5.488934839795978e-12

Min(Energy) = 5.488934775214590e-12

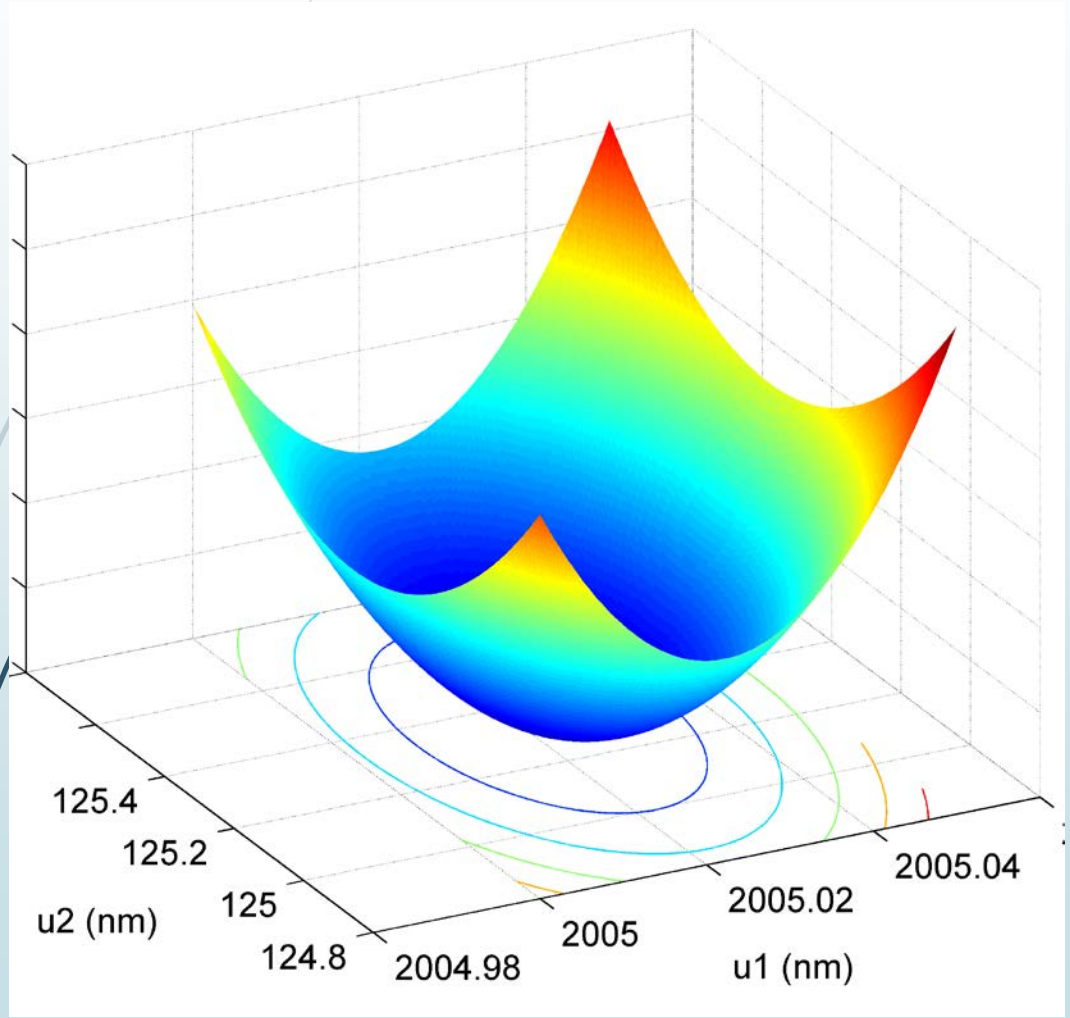
$$\begin{bmatrix} \text{Energy matrix} \end{bmatrix} - \text{Min(Energy)} = \begin{bmatrix} \text{New Energy matrix} \end{bmatrix}$$

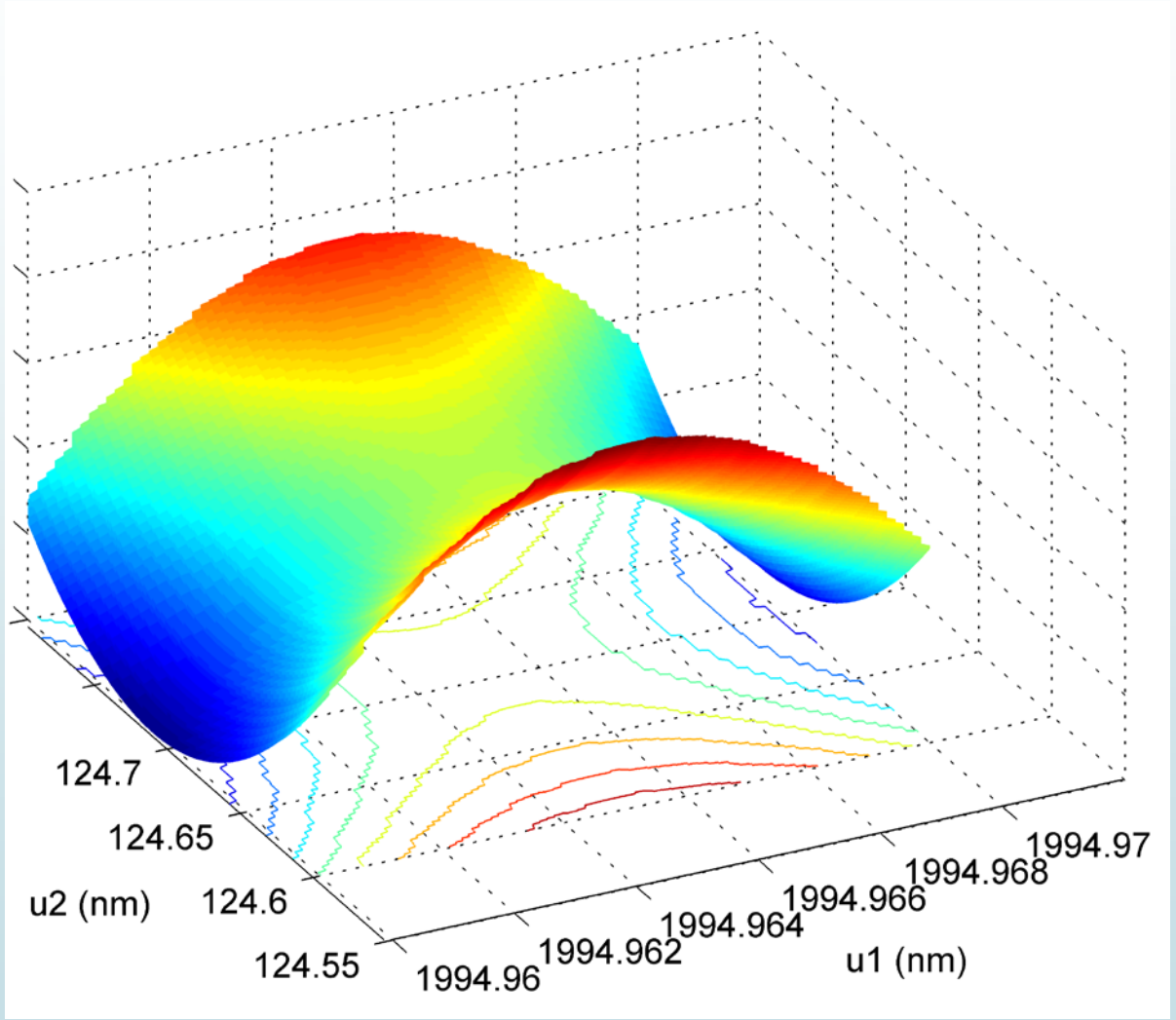
Soln of 2 DOF systems by energy landscape



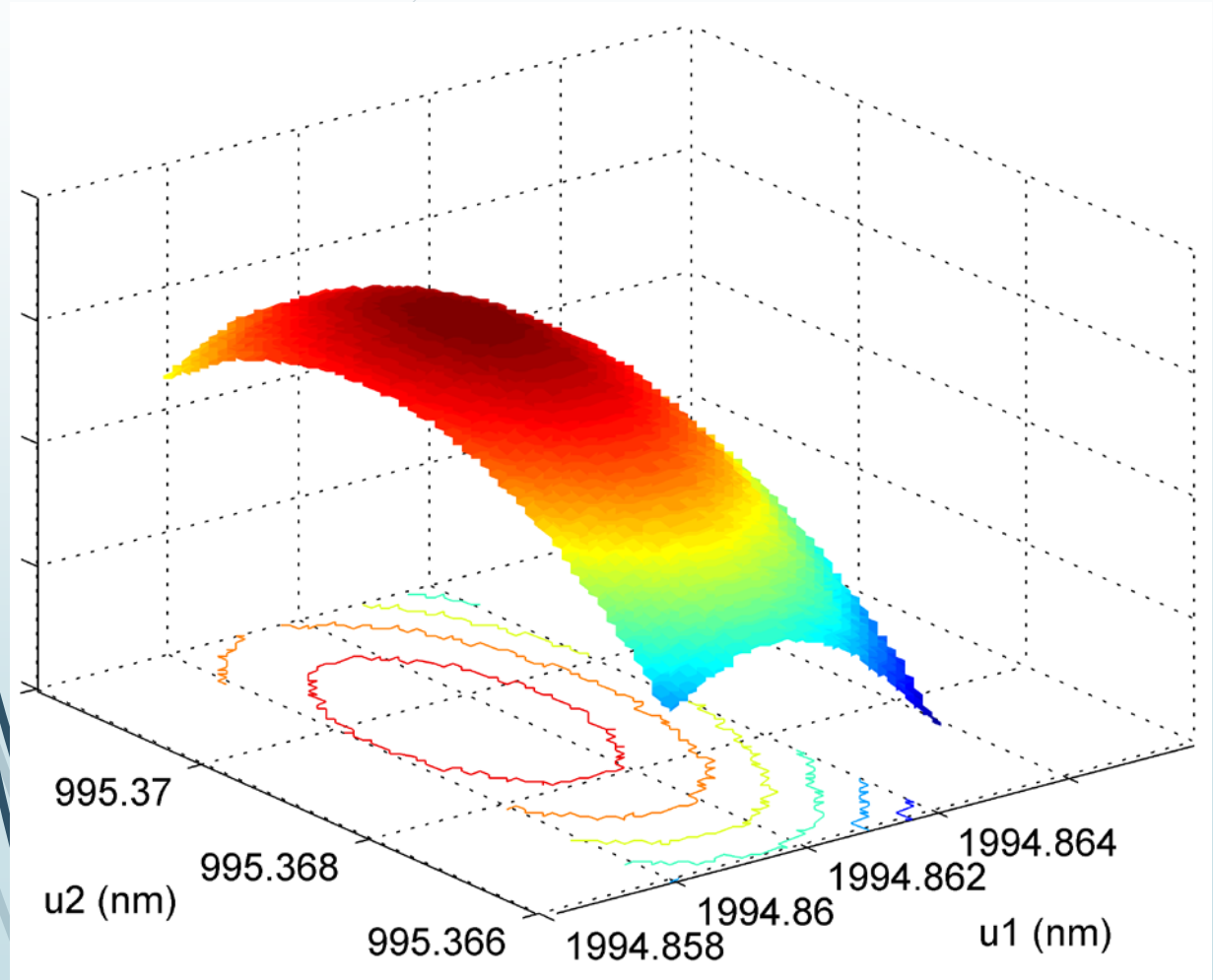


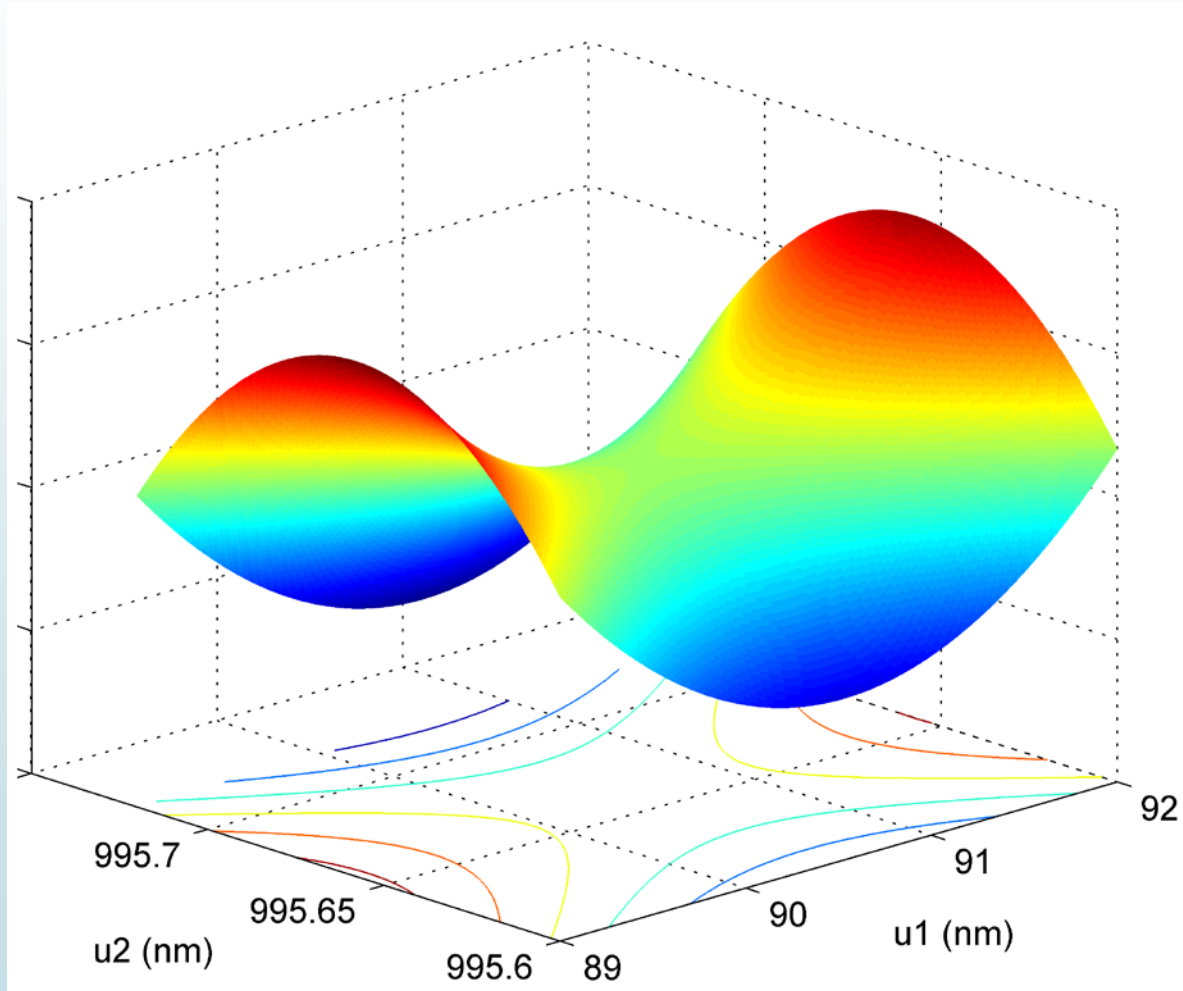
Sol^{n} of 2 DOF systems by energy landscape





Soln of 2 DOF systems by energy landscape





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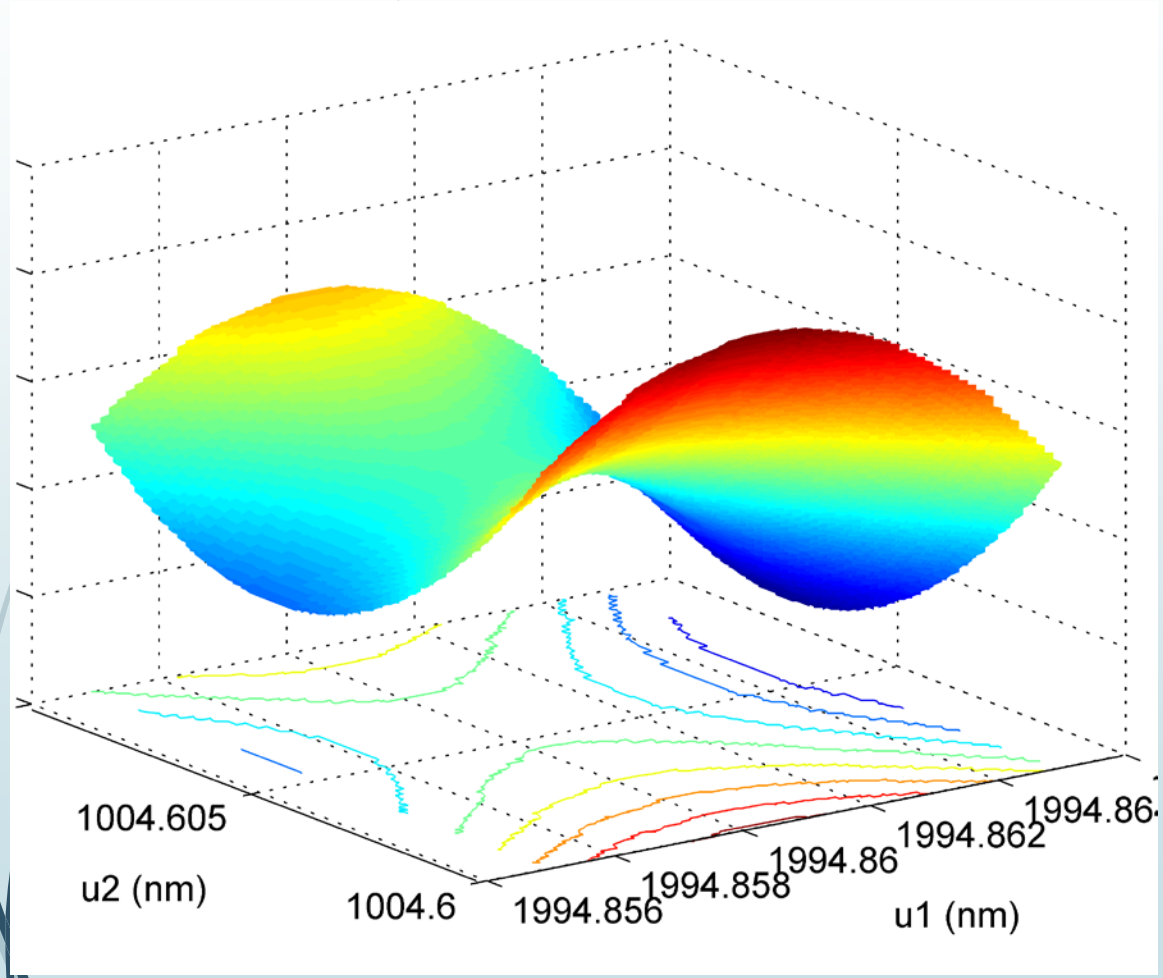

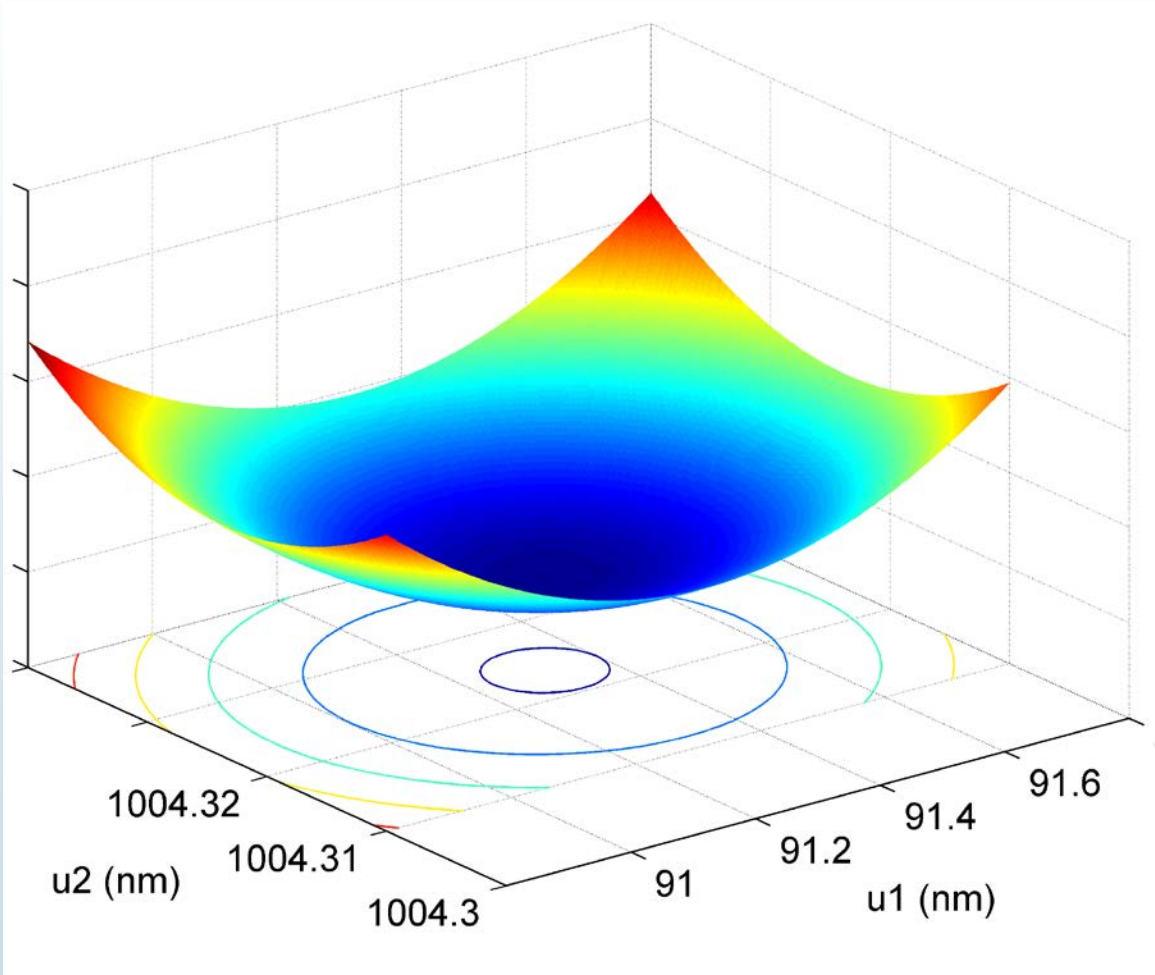

Dynamic pull-in 1DOF

MATLAB CODE

dynamic_pullin.m

THANK YOU…