



# 電腦輔助工程分析技術運用於數值控制 工具機的設計與分析

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機械設計工程系

雲林縣虎尾鎮文化路64號





底座



立柱

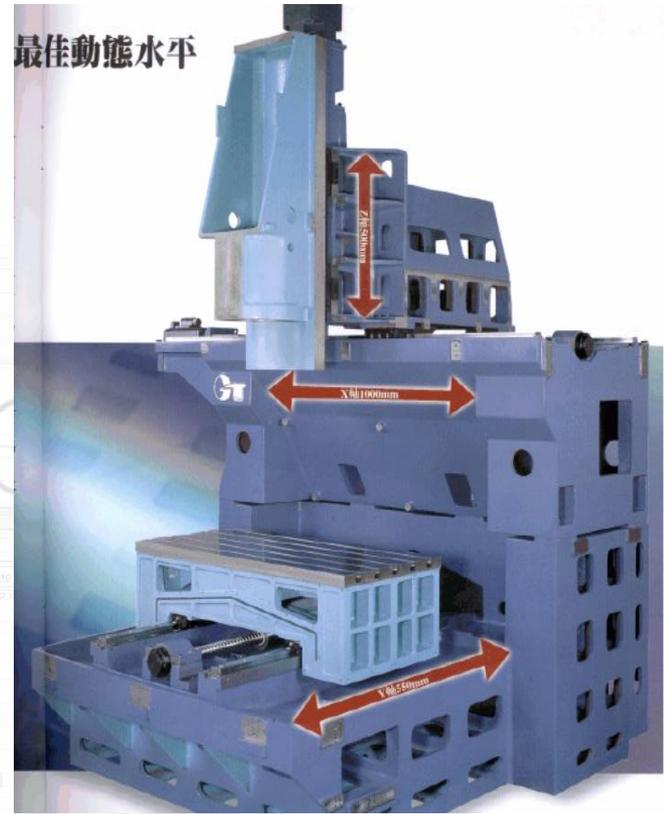
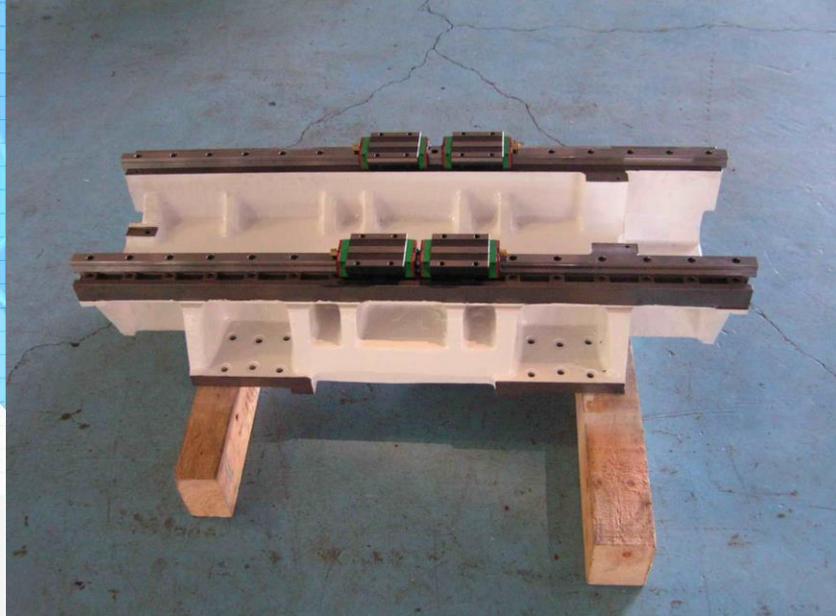


門型立柱





# • 壁型立柱



## 鞍座





工作台



頭部



主軸

1.12 was released on Sep 18th, 1999  
KDE Two meeting in Zilengen, Oct 7-18, 1999  
1.83 was released on Dec 15th, 1999  
1.90 (KDE beta1) May 11th, 2000 - 1.91 (KDE beta2) June 14th, 2000 - 1.92 (KDE beta3) July 25th, 2000  
  
KDE Three Beta meeting in Trondheim, Norway, July 9-19, 2000  
1.93 (KDE beta4) was released on August 23th, 2000  
04 docs GPL September 04th, 2000  
1.94 (KDE beta5) was released on September 15th, 2000  
2.0 Release Candidate was released on October 18th, 2000  
2.0 was released on October 23th, 2000  
2.0.1 was released on December 5th, 2000  
2.1 Beta 1 was released on December 16th, 2000





動態系統實驗室

Cast Iron  
Material  
Properties

Properties of Outline Row 4: Cast Iron FC30

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	7300	kg m <sup>-3</sup>	<input type="checkbox"/>	<input type="checkbox"/>
3	Isotropic Elasticity			<input type="checkbox"/>	
4	Derive from	Young's Mo...			
5	Young's Modulus	1.65E+05	MPa		<input type="checkbox"/>
6	Poisson's Ratio	0.23			<input type="checkbox"/>
7	Bulk Modulus	1.0185E+11	Pa		<input type="checkbox"/>
8	Shear Modulus	6.7073E+10	Pa		<input type="checkbox"/>

Properties of Outline Row 3: Cast Iron

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	7300	kg m <sup>-3</sup>	<input type="checkbox"/>	<input type="checkbox"/>
3	Isotropic Elasticity			<input type="checkbox"/>	
4	Derive from	Young's Mo...			
5	Young's Modulus	70000	MPa		<input type="checkbox"/>
6	Poisson's Ratio	0.23			<input type="checkbox"/>
7	Bulk Modulus	4.321E+10	Pa		<input type="checkbox"/>
8	Shear Modulus	2.8455E+10	Pa		<input type="checkbox"/>



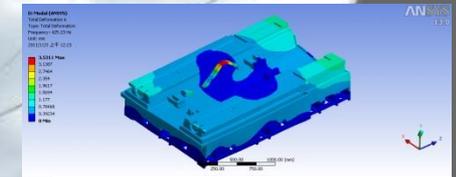
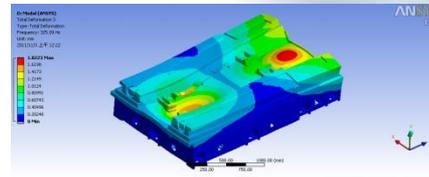
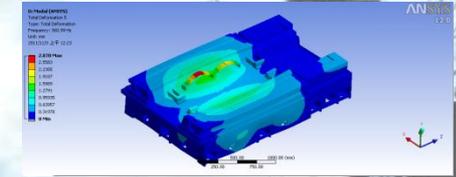
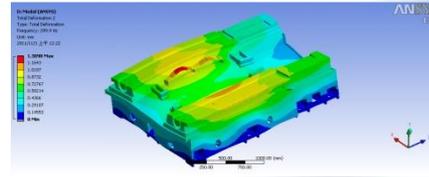
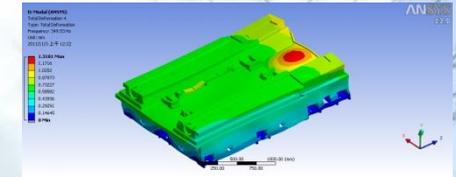
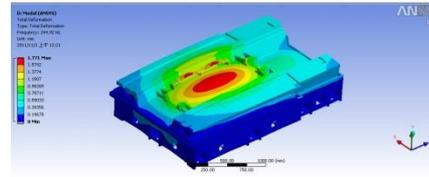
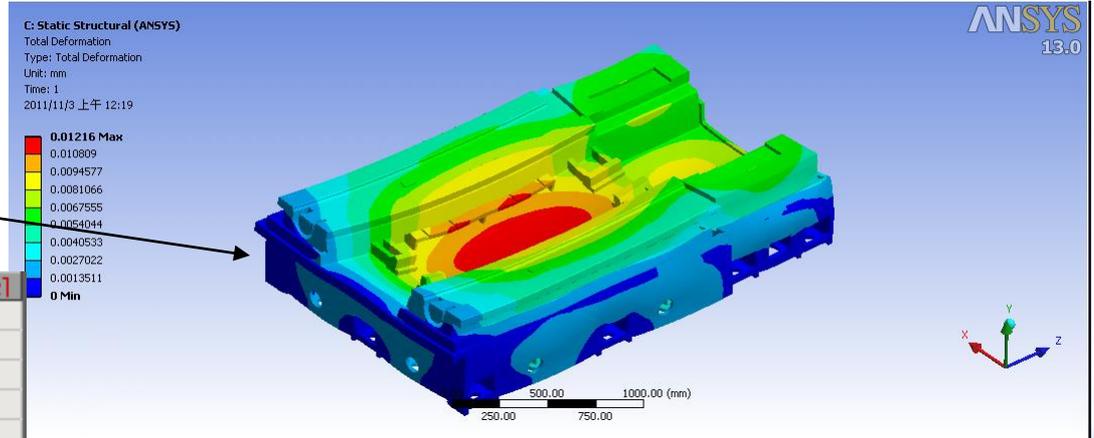
動態系統實驗室

底座  
原始設計

受自然重力和其他鑄件重量

	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	244.92
2	2.	299.9
3	3.	325.09
4	4.	349.53
5	5.	360.99
6	6.	425.23
7	7.	434.53
8	8.	456.08
9	9.	508.94
10	10.	516.44
11	11.	559.22
12	12.	563.9
13	13.	598.7
14	14.	615.15
15	15.	630.41
16	16.	639.49
17	17.	642.73
18	18.	660.22
19	19.	671.74
20	20.	674.72

	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	159.52
2	2.	195.34
3	3.	211.74
4	4.	227.66
5	5.	235.13
6	6.	276.97
7	7.	283.02
8	8.	297.06
9	9.	331.49
10	10.	336.38
11	11.	364.24
12	12.	367.29
13	13.	389.94
14	14.	400.67
15	15.	410.6
16	16.	416.52
17	17.	418.63
18	18.	430.02
19	19.	437.56
20	20.	439.5

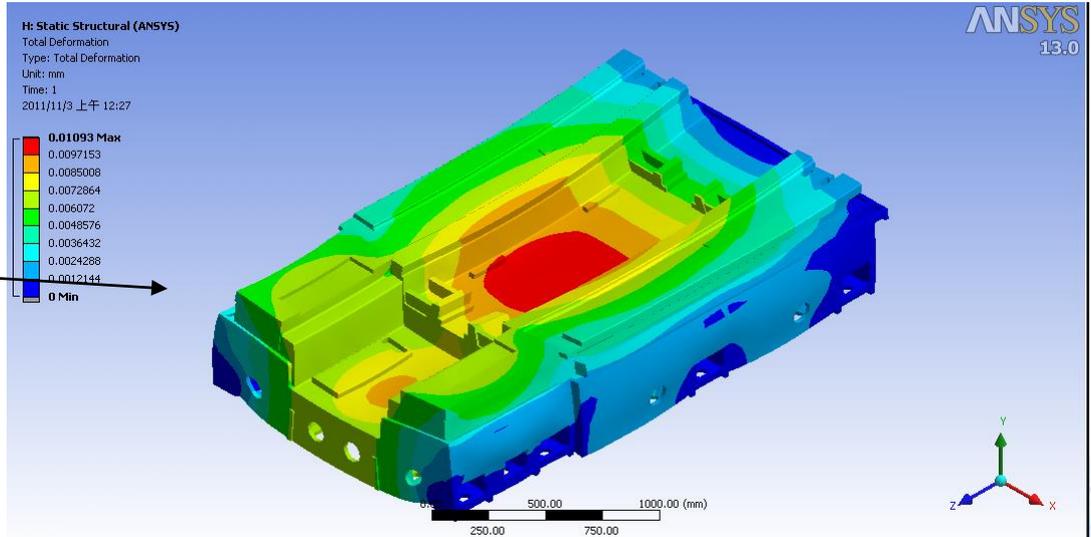




動態系統實驗室

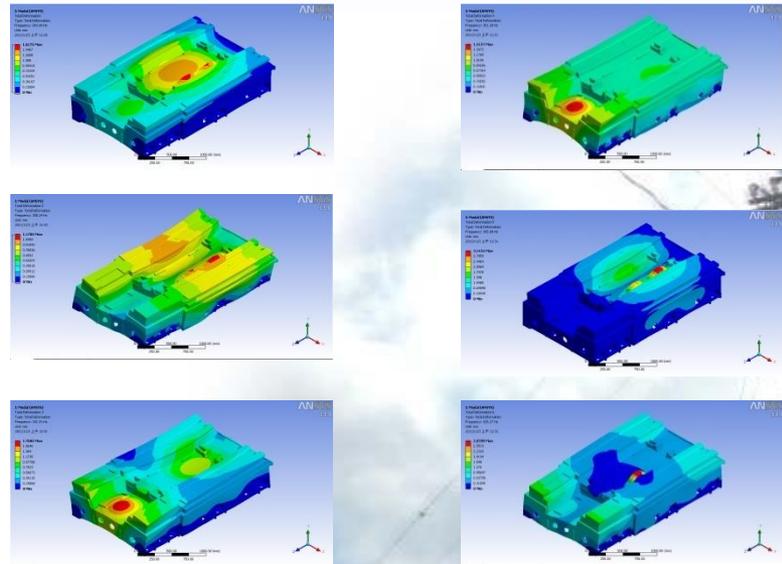
底座  
改善設計

受自然重力和其他鑄件重量



	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	249.99
2	2.	308.24
3	3.	331.91
4	4.	351.28
5	5.	365.88
6	6.	426.27
7	7.	436.24
8	8.	483.8
9	9.	507.27
10	10.	523.42
11	11.	563.33
12	12.	600.62
13	13.	613.66
14	14.	628.48
15	15.	636.22
16	16.	646.46
17	17.	658.71
18	18.	673.89
19	19.	674.88
20	20.	676.96

	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	162.82
2	2.	200.77
3	3.	216.18
4	4.	228.8
5	5.	238.31
6	6.	277.64
7	7.	284.13
8	8.	315.11
9	9.	330.4
10	10.	340.92
11	11.	366.91
12	12.	391.19
13	13.	399.7
14	14.	409.35
15	15.	414.39
16	16.	421.06
17	17.	429.04
18	18.	438.96
19	19.	439.61
20	20.	440.96





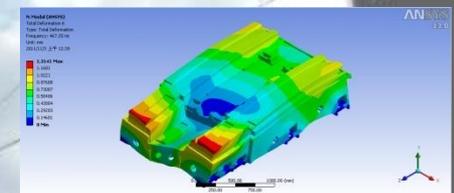
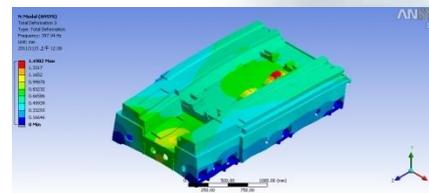
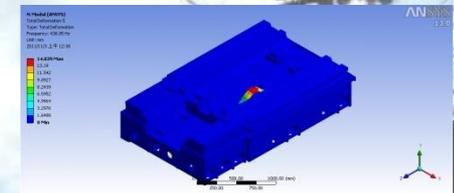
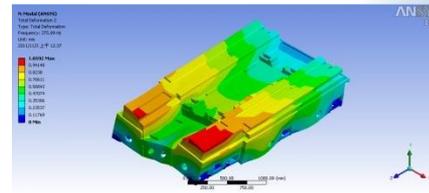
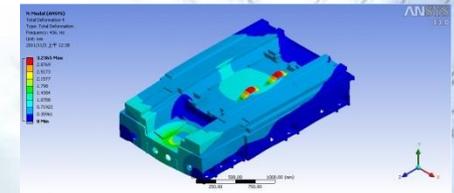
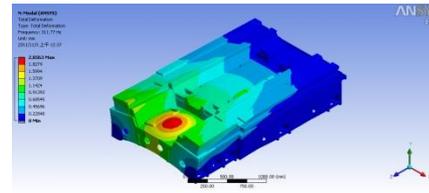
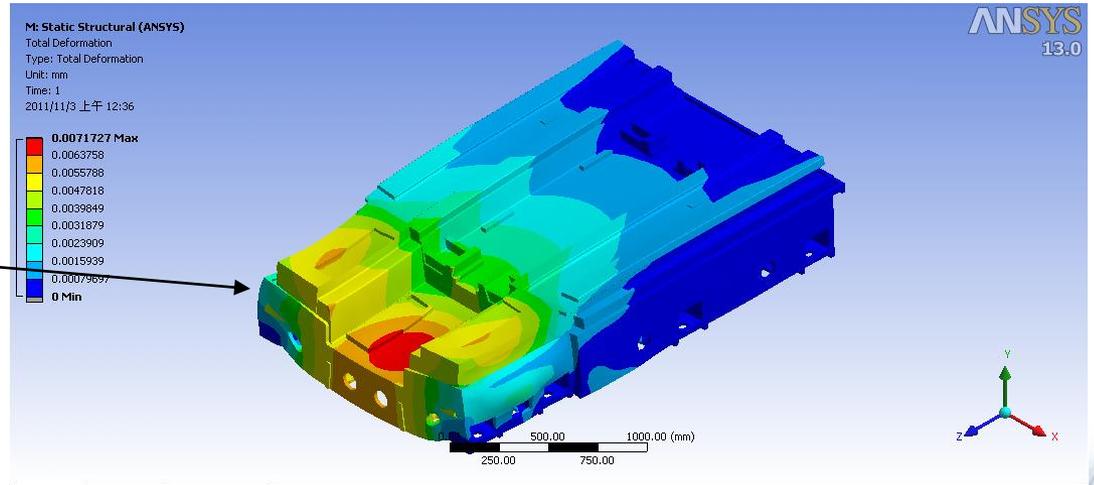
### 動態系統實驗室

## 底座 十字肋設計

受自然重力和其他鑄件重量

	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	311.77
2	2.	375.89
3	3.	397.94
4	4.	436.
5	5.	438.85
6	6.	467.25
7	7.	504.77
8	8.	585.36
9	9.	607.5
10	10.	623.86
11	11.	648.24
12	12.	657.13
13	13.	667.08
14	14.	679.11
15	15.	696.13
16	16.	709.82
17	17.	722.19
18	18.	775.5
19	19.	821.01
20	20.	886.03

	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	201.92
2	2.	238.34
3	3.	254.46
4	4.	281.35
5	5.	285.82
6	6.	299.12
7	7.	328.54
8	8.	375.89
9	9.	384.14
10	10.	396.03
11	11.	416.43
12	12.	424.77
13	13.	427.76
14	14.	442.08
15	15.	449.97
16	16.	462.05
17	17.	467.75
18	18.	472.08
19	19.	517.26
20	20.	573.88



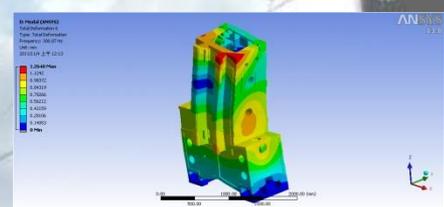
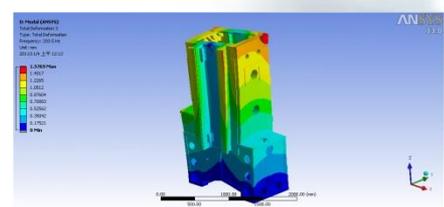
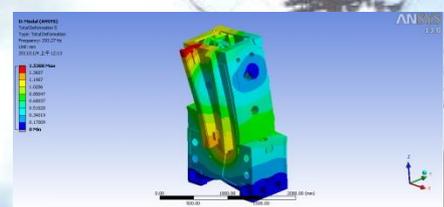
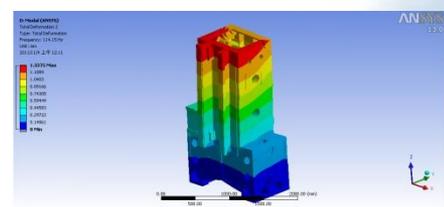
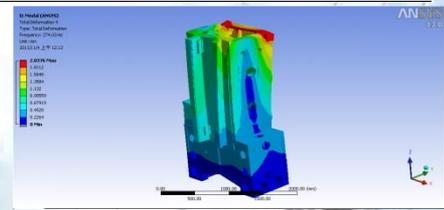
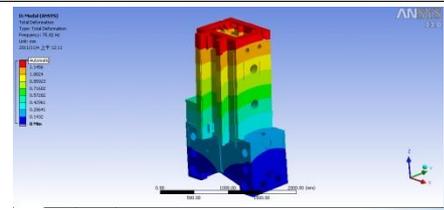
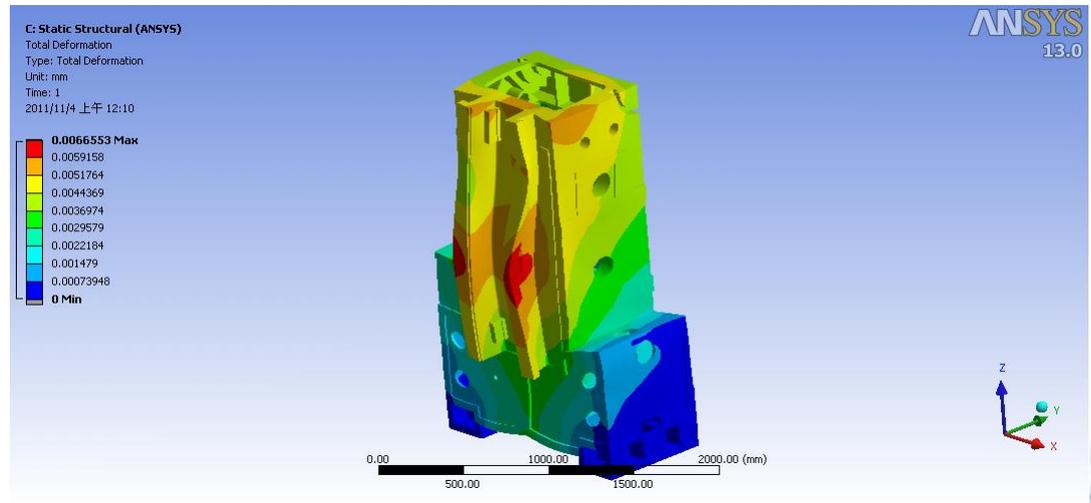


動態系統實驗室

立柱

	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	75.82
2	2.	114.15
3	3.	203.5
4	4.	274.03
5	5.	293.27
6	6.	300.87
7	7.	324.22
8	8.	343.02
9	9.	378.12
10	10.	404.54
11	11.	418.76
12	12.	489.98
13	13.	526.68
14	14.	542.49
15	15.	548.15
16	16.	558.03
17	17.	565.03
18	18.	586.08
19	19.	611.78
20	20.	644.82

	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	49.383
2	2.	74.347
3	3.	132.55
4	4.	178.48
5	5.	191.02
6	6.	195.96
7	7.	211.18
8	8.	223.42
9	9.	246.28
10	10.	263.5
11	11.	272.76
12	12.	319.14
13	13.	343.05
14	14.	353.34
15	15.	357.03
16	16.	363.46
17	17.	368.02
18	18.	381.73
19	19.	398.47
20	20.	419.99





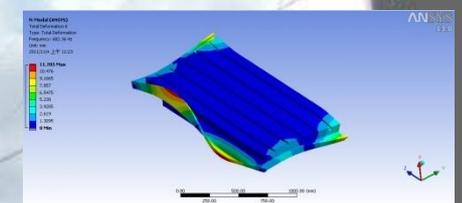
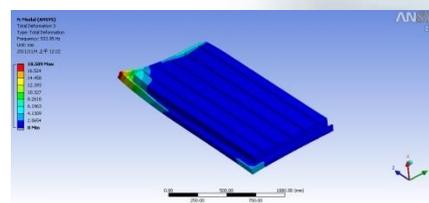
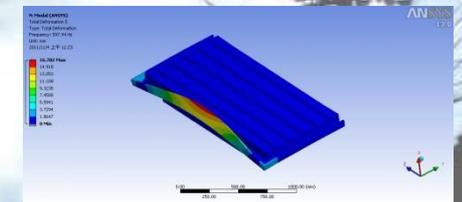
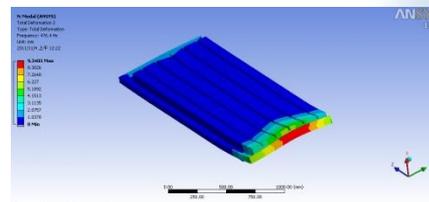
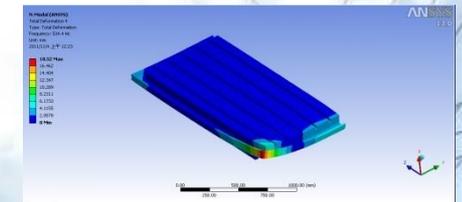
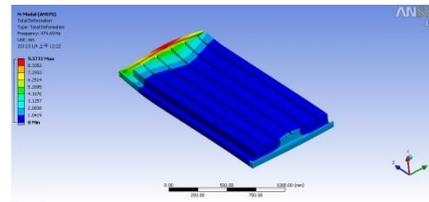
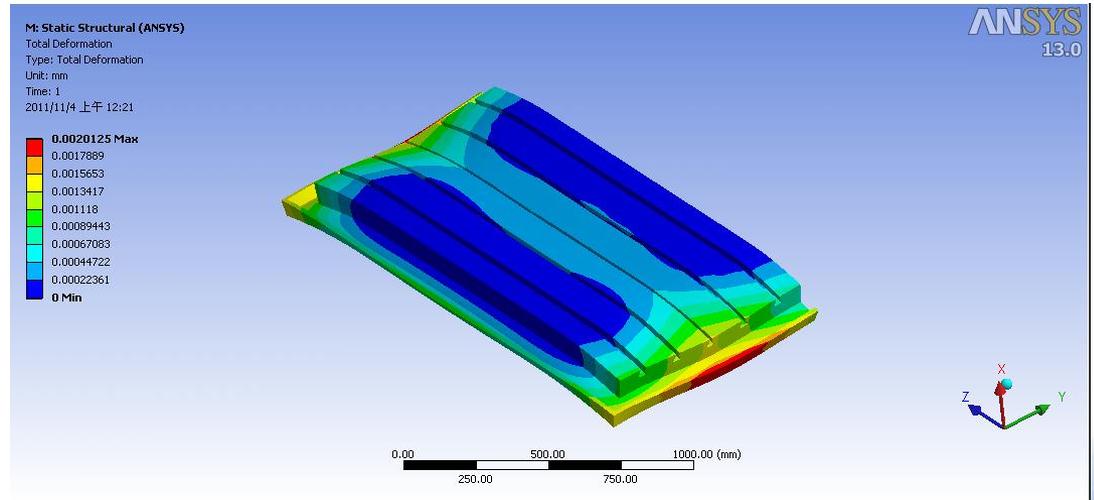


動態系統實驗室

工作台

	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	474.69
2	2.	476.4
3	3.	533.95
4	4.	534.4
5	5.	597.94
6	6.	682.36
7	7.	715.92
8	8.	735.69
9	9.	836.56
10	10.	860.44
11	11.	900.35
12	12.	918.97
13	13.	930.04
14	14.	1003.
15	15.	1011.8
16	16.	1095.
17	17.	1123.7
18	18.	1142.5
19	19.	1167.1
20	20.	1235.9

	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	309.18
2	2.	310.3
3	3.	347.79
4	4.	348.08
5	5.	389.46
6	6.	444.45
7	7.	466.31
8	8.	479.18
9	9.	544.89
10	10.	560.44
11	11.	586.43
12	12.	598.56
13	13.	605.77
14	14.	653.32
15	15.	659.03
16	16.	713.23
17	17.	731.9
18	18.	744.12
19	19.	760.18
20	20.	805.01



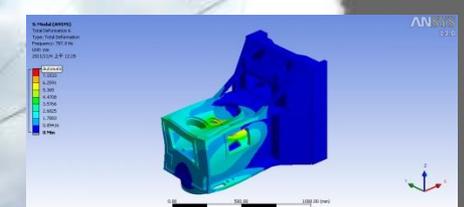
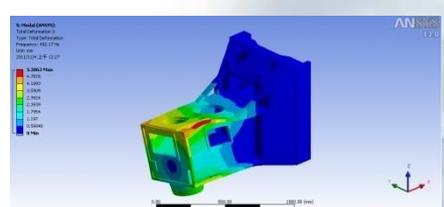
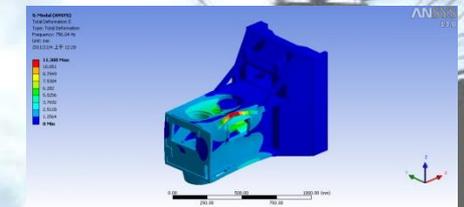
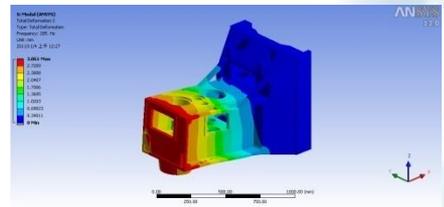
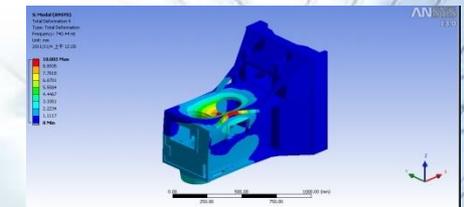
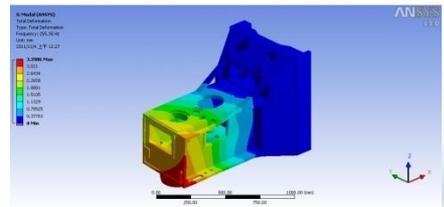
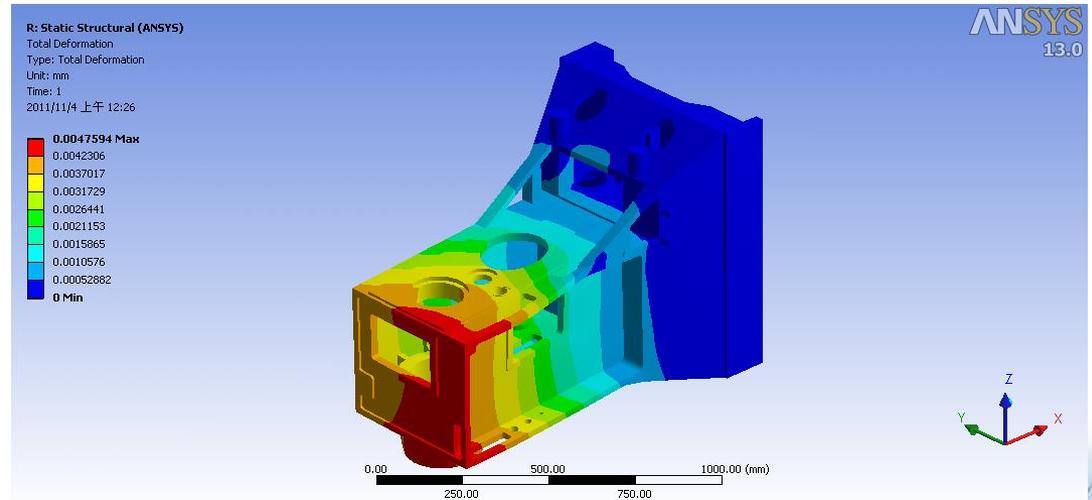


### 動態系統實驗室

## 齒輪式主軸頭

	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	255.35
2	2.	285.
3	3.	492.17
4	4.	740.44
5	5.	756.04
6	6.	787.9
7	7.	822.61
8	8.	870.91
9	9.	890.11
10	10.	936.6
11	11.	1161.3
12	12.	1210.6
13	13.	1247.7
14	14.	1260.6
15	15.	1287.7
16	16.	1303.6
17	17.	1341.7
18	18.	1353.6
19	19.	1372.2
20	20.	1410.

	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	166.32
2	2.	185.63
3	3.	320.57
4	4.	482.28
5	5.	492.44
6	6.	513.19
7	7.	535.8
8	8.	567.26
9	9.	579.77
10	10.	610.04
11	11.	756.39
12	12.	788.51
13	13.	812.69
14	14.	821.06
15	15.	838.74
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17	17.	873.91
18	18.	881.64
19	19.	893.79
20	20.	918.39



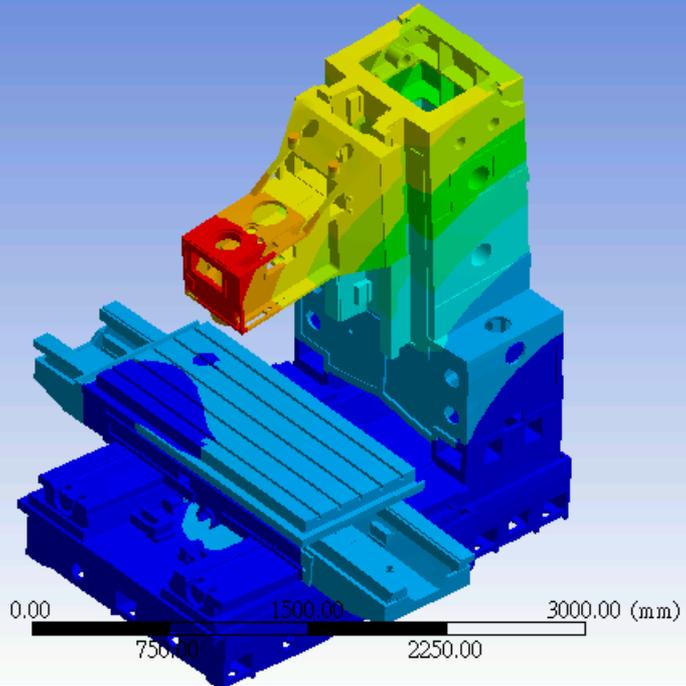
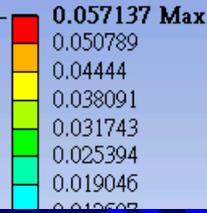


動態系統實驗室

原始設計

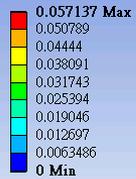
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Total Deformation  
Type: Total Deformation  
Unit: mm  
Time: 1  
2011/10/27 下午 08:59



B: Static Structural (ANSYS)

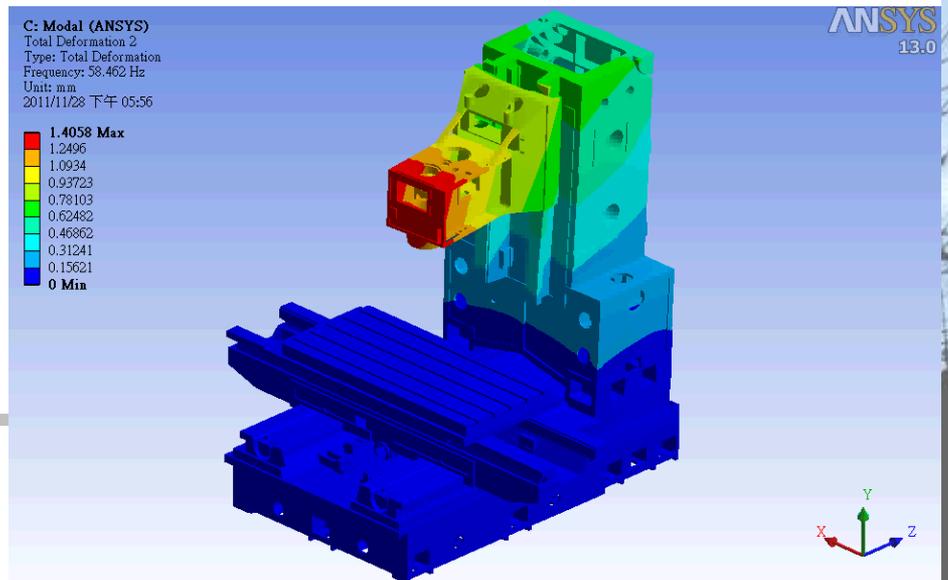
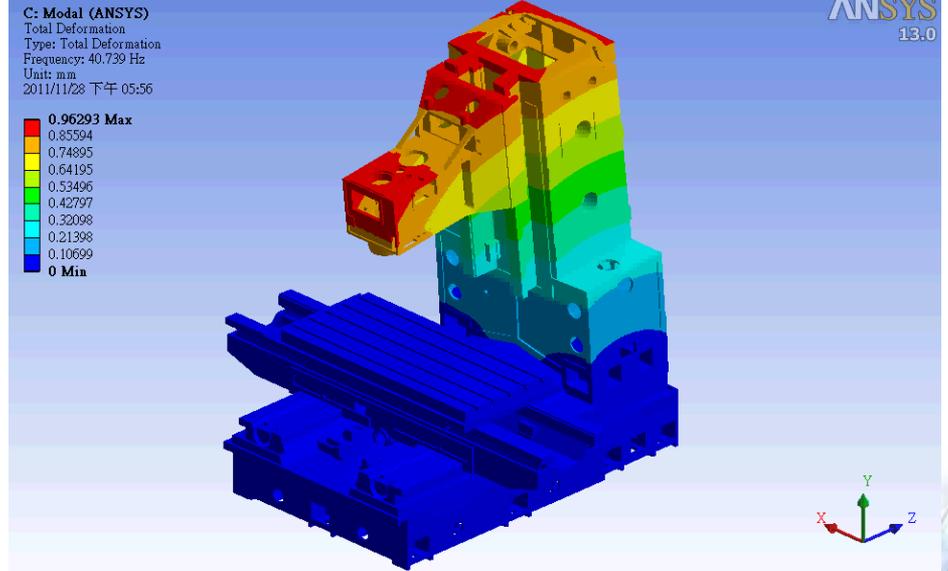
Total Deformation  
Type: Total Deformation  
Unit: mm  
Time: 1  
2011/10/27 下午 08:59





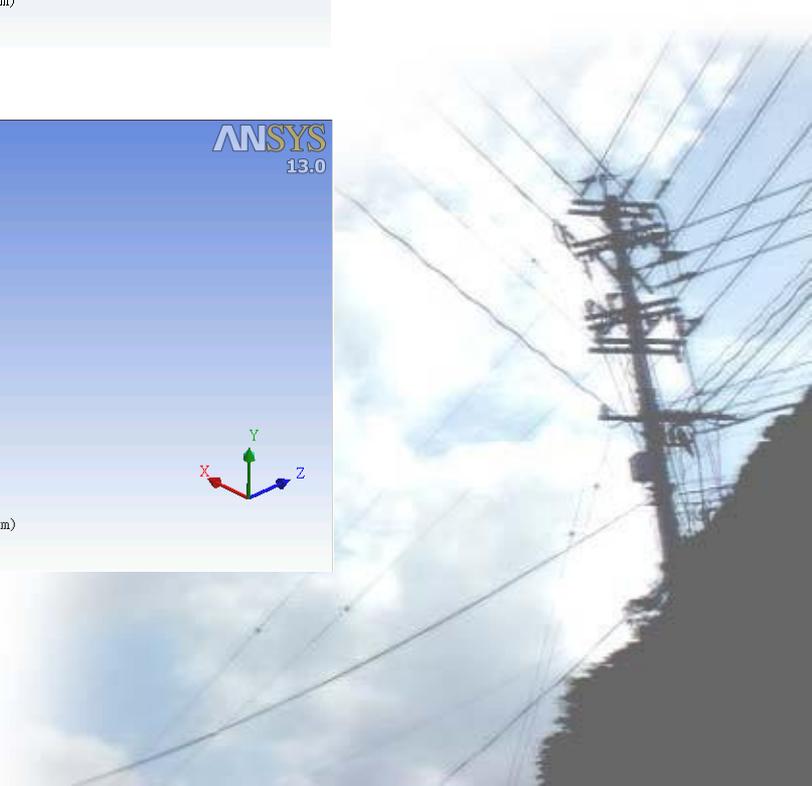
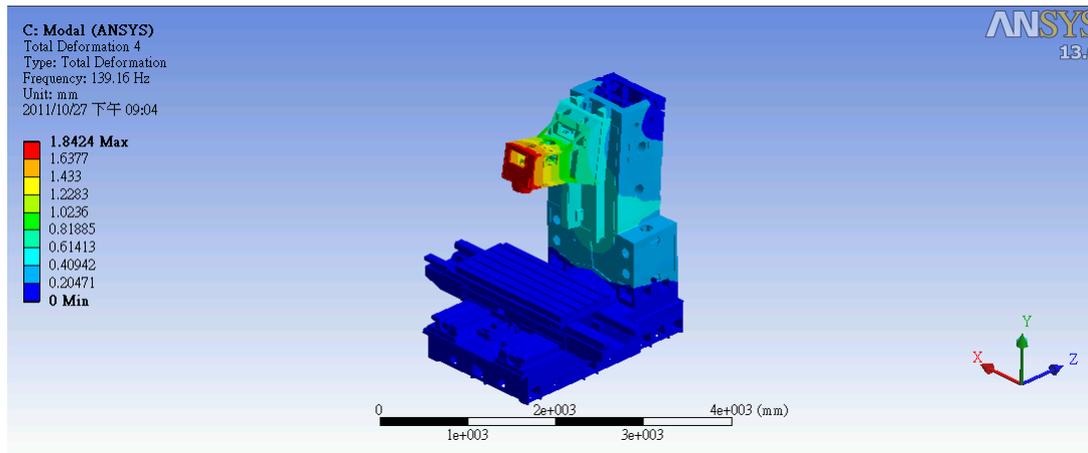
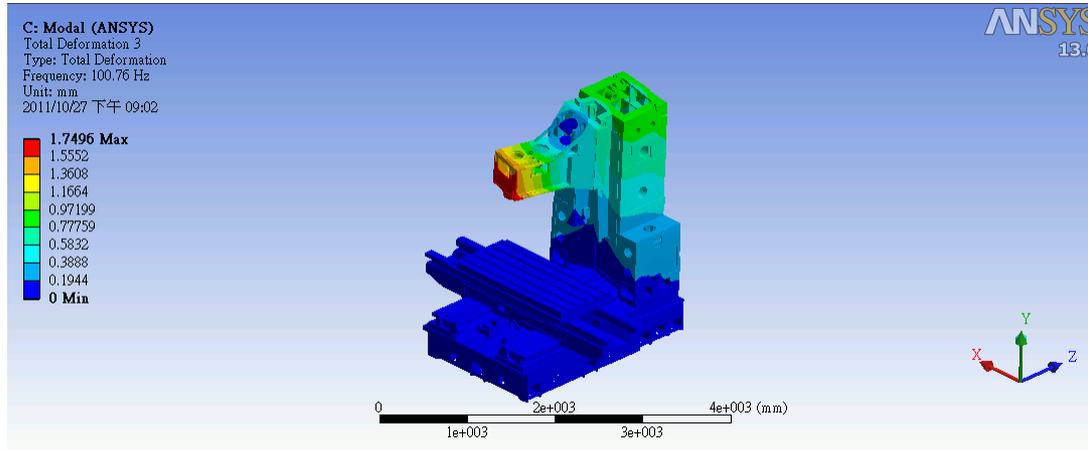
動態系統實驗室

	Mode	<input checked="" type="checkbox"/> Frequency [Hz]		Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	40.739	1	1.	26.533
2	2.	58.462	2	2.	38.078
3	3.	100.76	3	3.	65.63
4	4.	139.16	4	4.	90.641
5	5.	158.15	5	5.	103.01
6	6.	183.14	6	6.	119.28
7	7.	191.91	7	7.	125.
8	8.	204.21	8	8.	133.01
9	9.	213.79	9	9.	139.25
10	10.	234.29	10	10.	152.6
11	11.	244.79	11	11.	159.44
12	12.	263.18	12	12.	171.42
13	13.	269.38	13	13.	175.46
14	14.	306.64	14	14.	199.73
15	15.	323.65	15	15.	210.81
16	16.	337.11	16	16.	219.57
17	17.	343.31	17	17.	223.61
18	18.	370.65	18	18.	241.42
19	19.	373.6	19	19.	243.34
20	20.	391.	20	20.	254.67



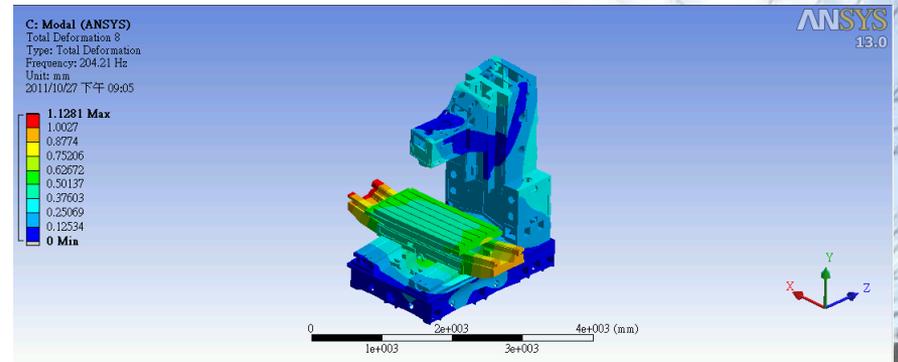
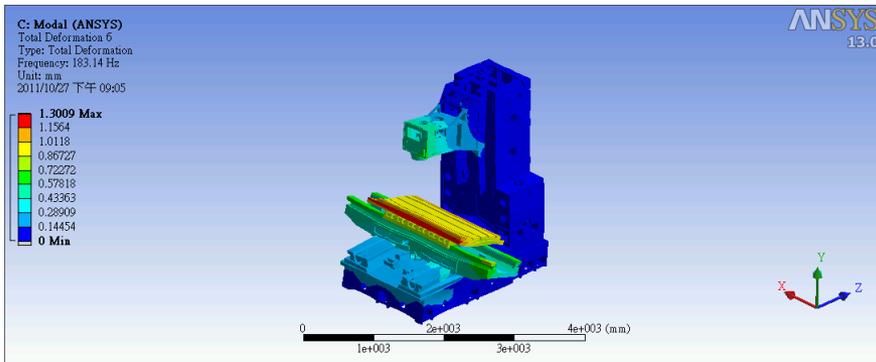
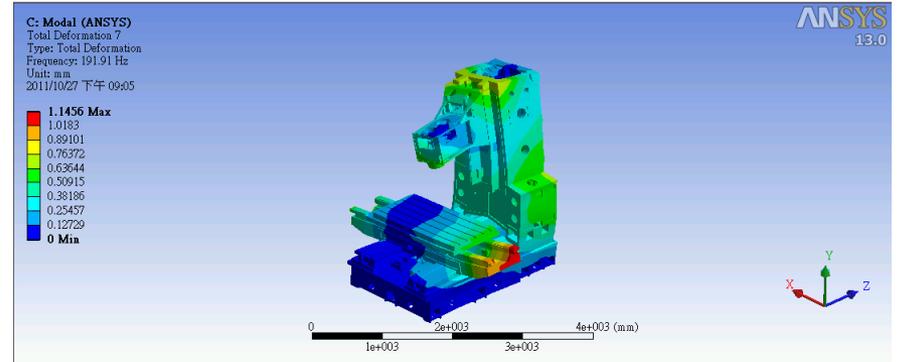
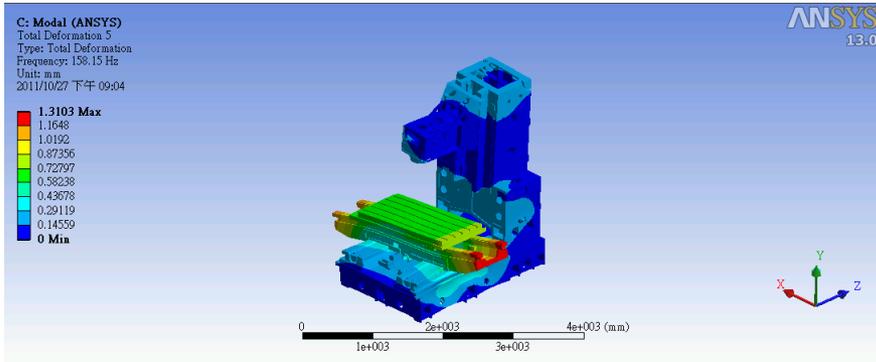


動態系統實驗室



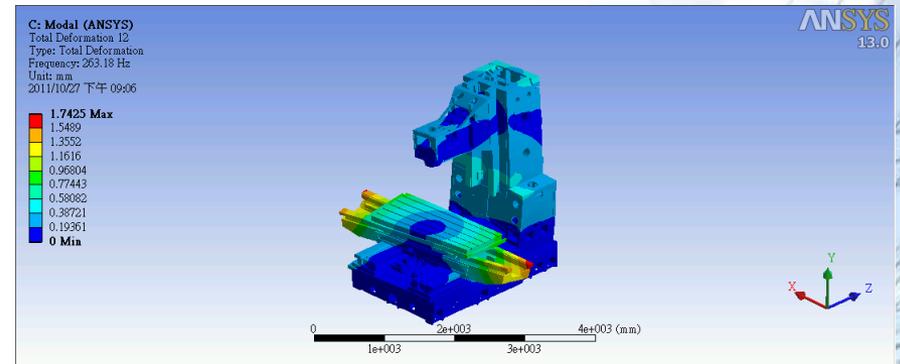
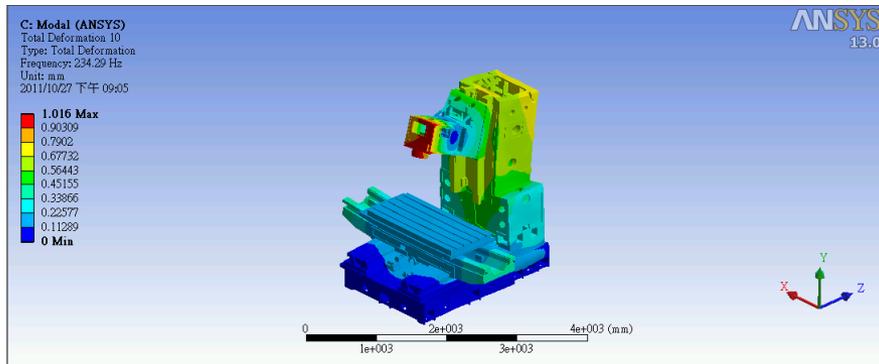
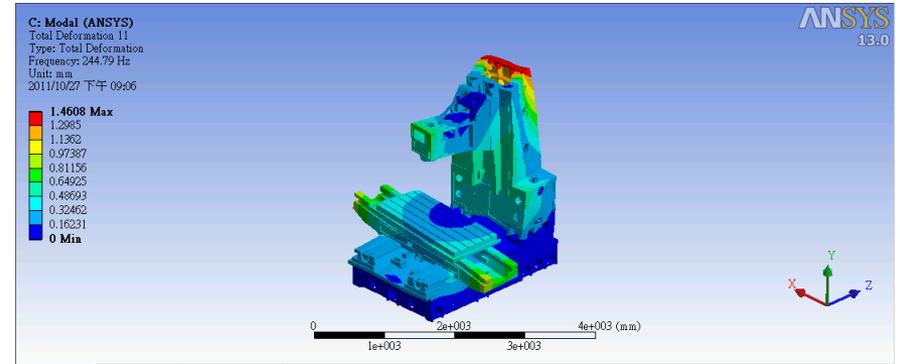
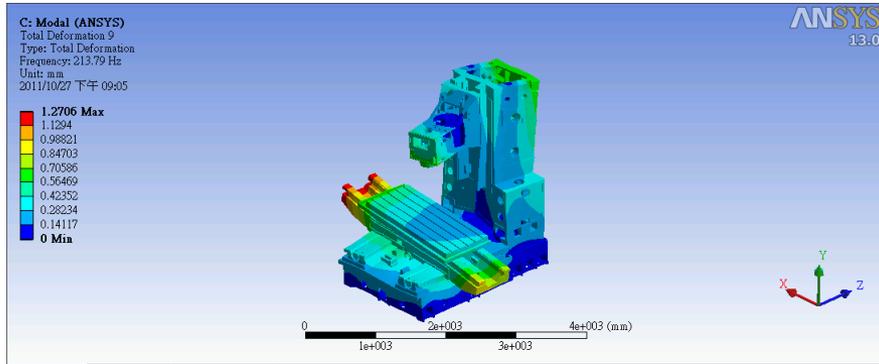


動態系統實驗室



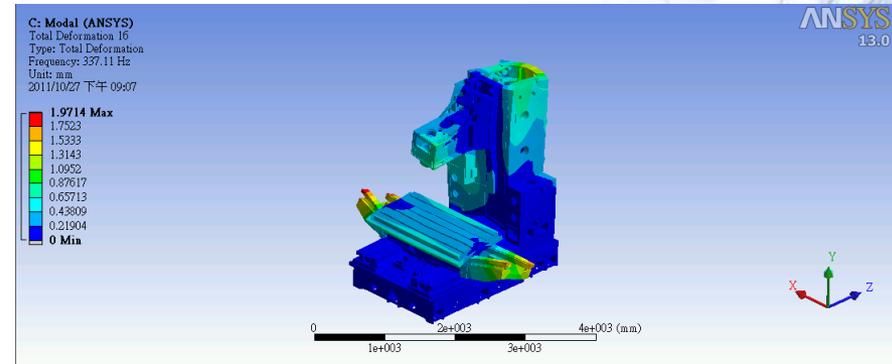
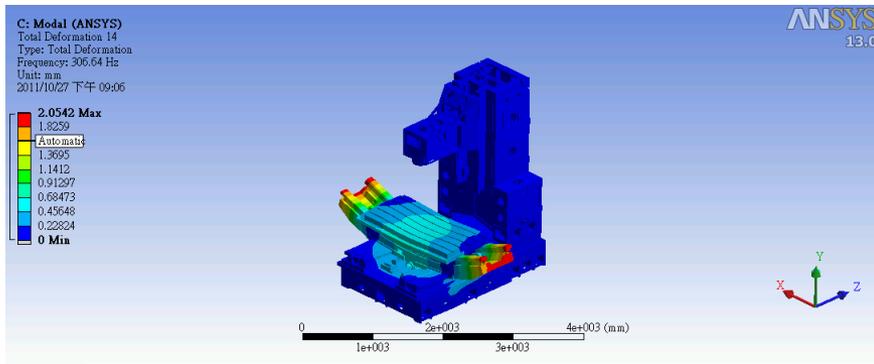
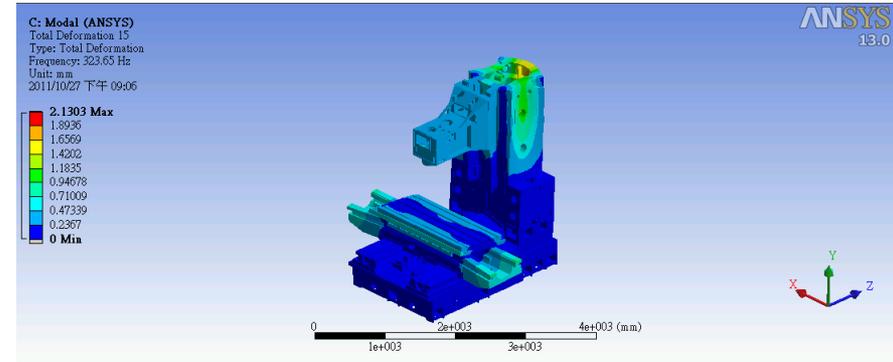
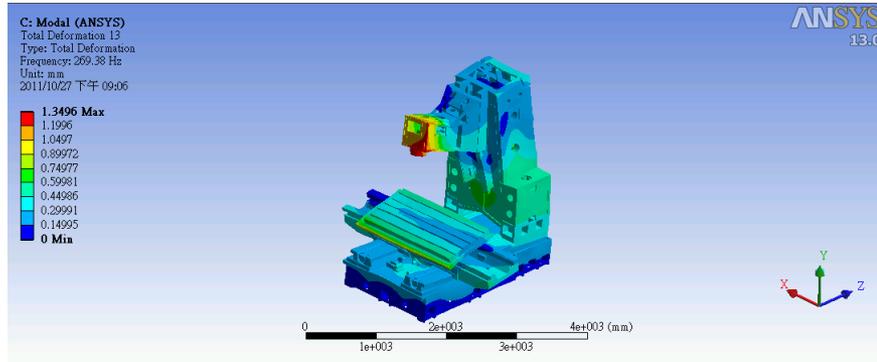


動態系統實驗室



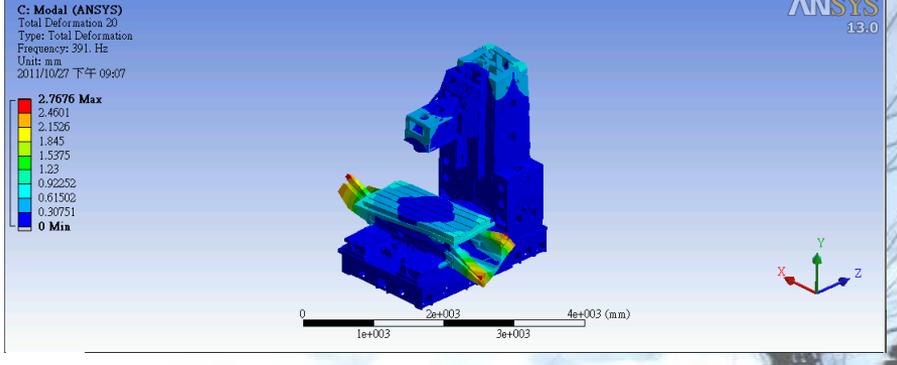
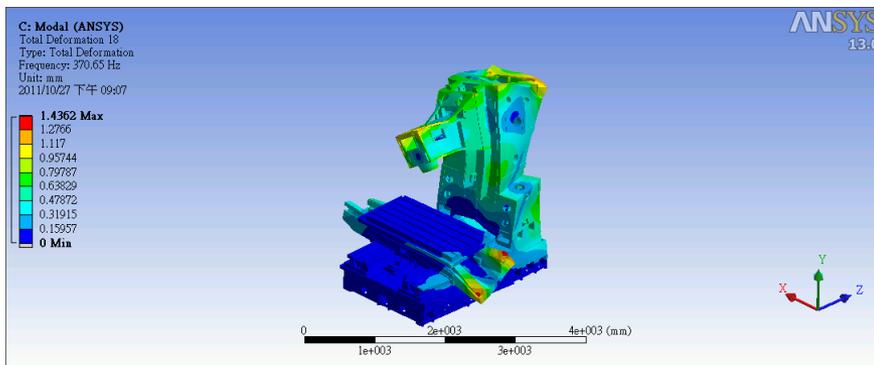
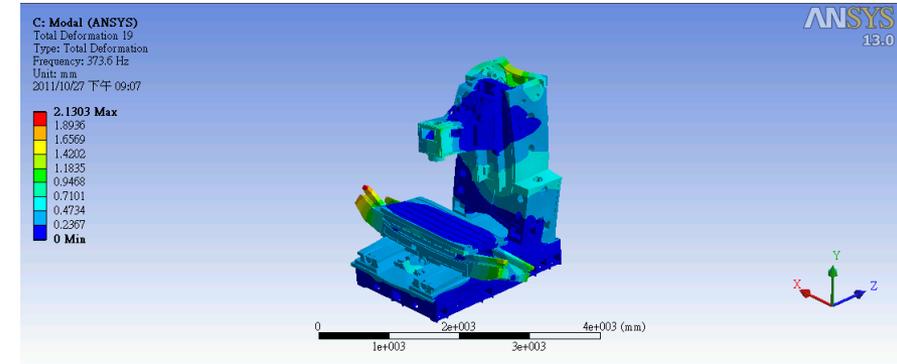
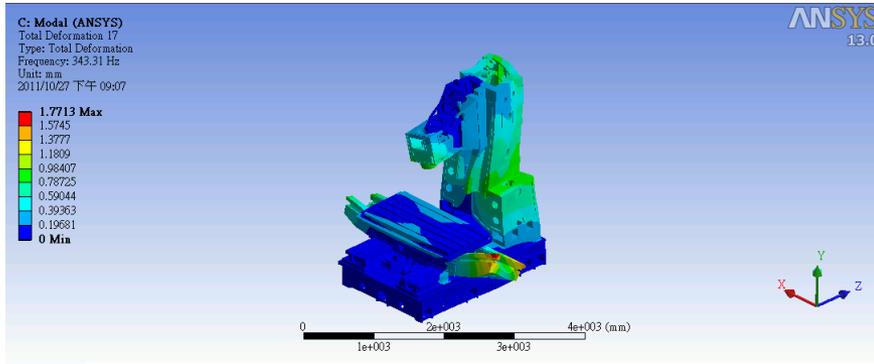


動態系統實驗室





動態系統實驗室



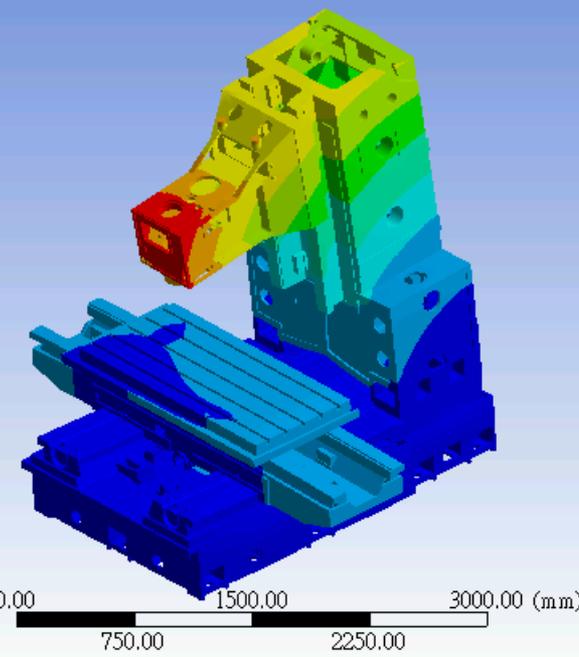


動態系統實驗室

改善設計\_部分加肋

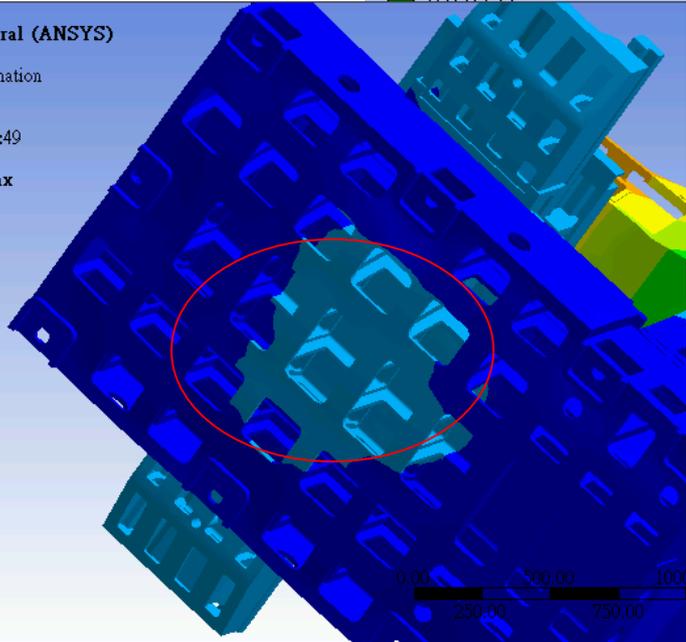
B: Static Structural (ANSYS)

Total Deformation  
Type: Total Deformation  
Unit: mm  
Time: 1  
2011/11/2 下午 11:49



B: Static Structural (ANSYS)

Total Deformation  
Type: Total Deformation  
Unit: mm  
Time: 1  
2011/11/2 下午 11:49

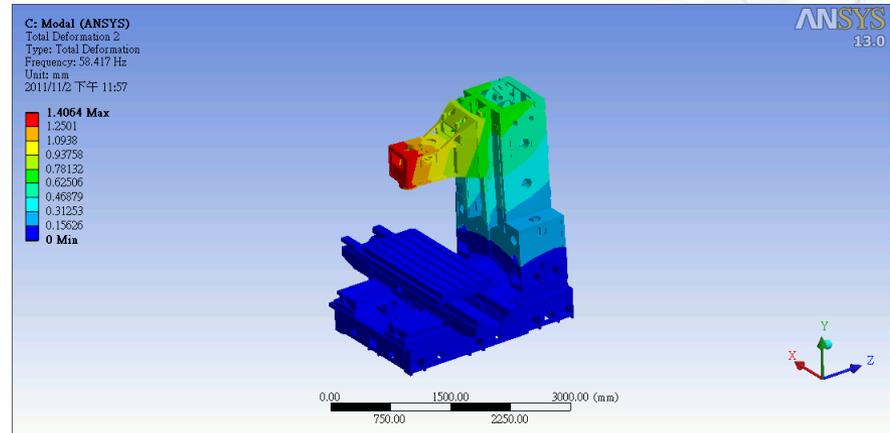
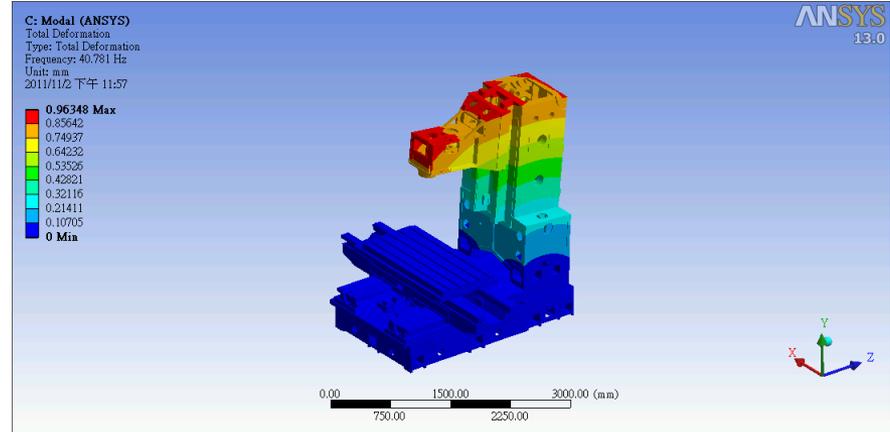




動態系統實驗室

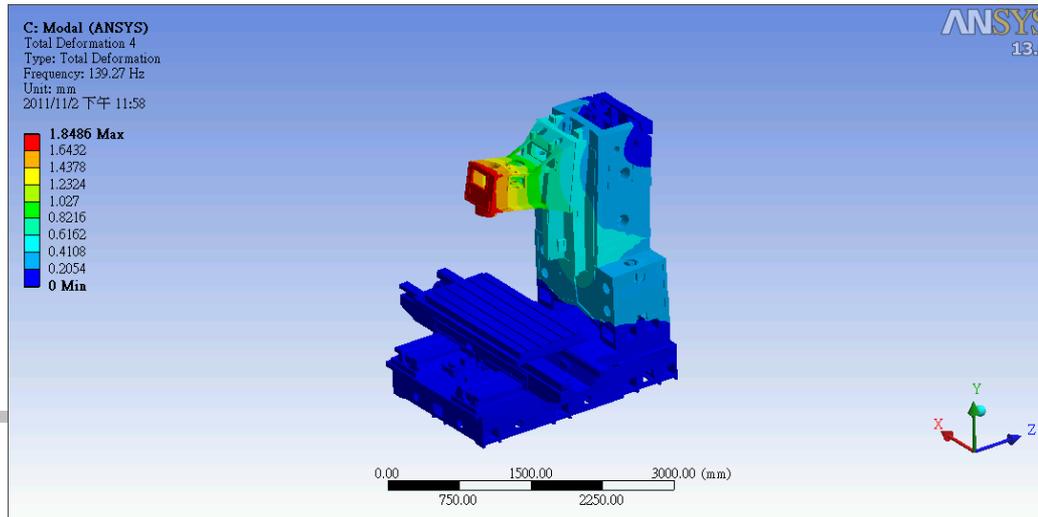
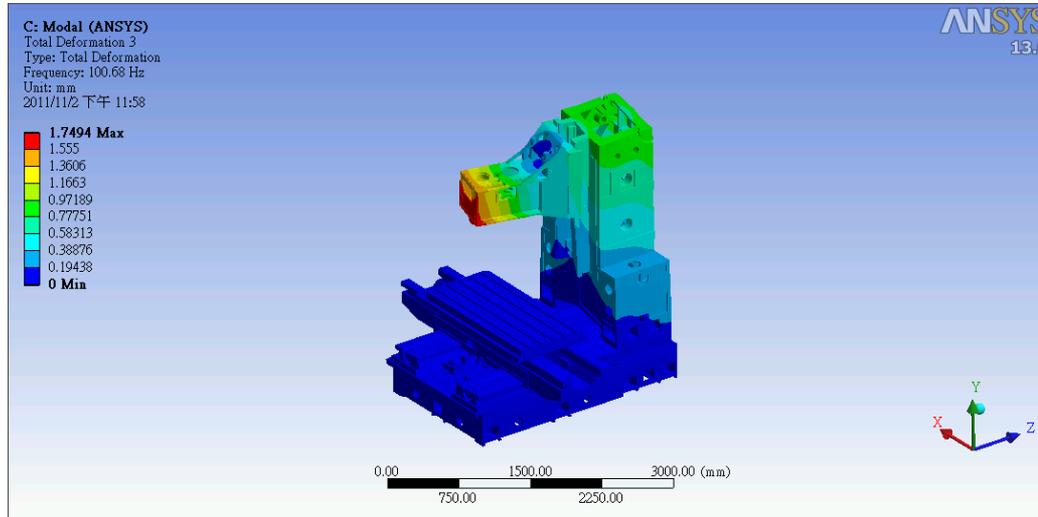
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5	5.	158.36
6	6.	185.27
7	7.	192.69
8	8.	205.56
9	9.	216.02
10	10.	234.45
11	11.	245.32
12	12.	263.77
13	13.	269.97
14	14.	303.57
15	15.	323.64
16	16.	337.14
17	17.	342.91
18	18.	370.61
19	19.	373.5
20	20.	389.89

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3	3.	65.579
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5	5.	103.15
6	6.	120.67
7	7.	125.51
8	8.	133.89
9	9.	140.7
10	10.	152.71
11	11.	159.79
12	12.	171.8
13	13.	175.84
14	14.	197.73
15	15.	210.8
16	16.	219.59
17	17.	223.35
18	18.	241.39
19	19.	243.28
20	20.	253.95



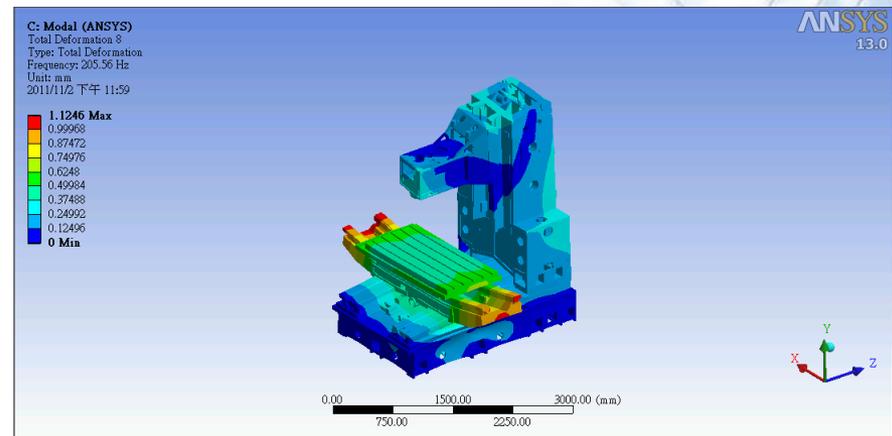
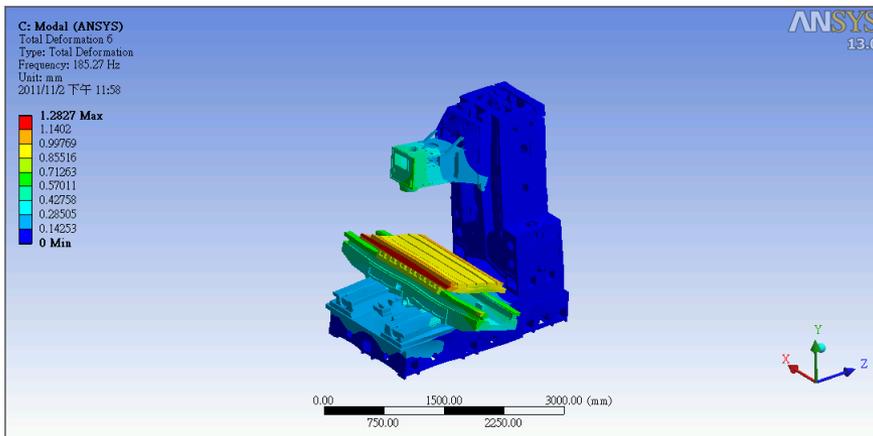
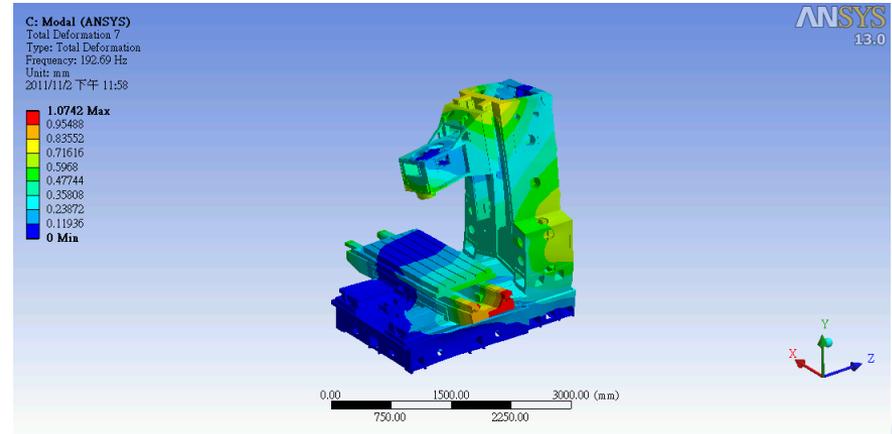
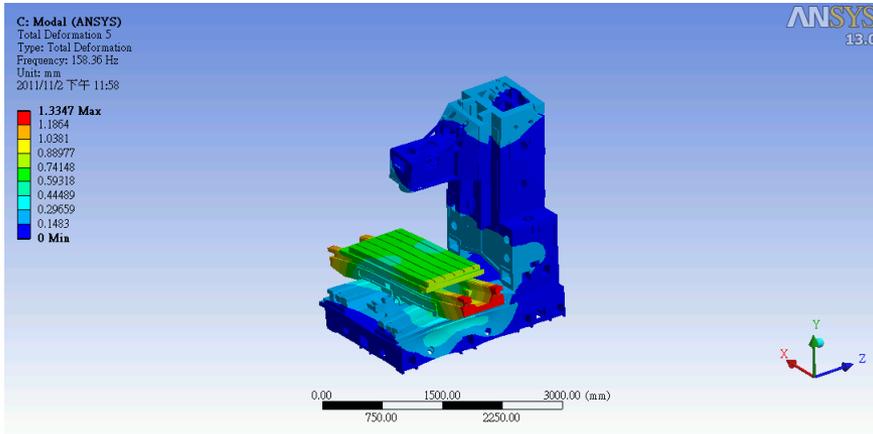


動態系統實驗室



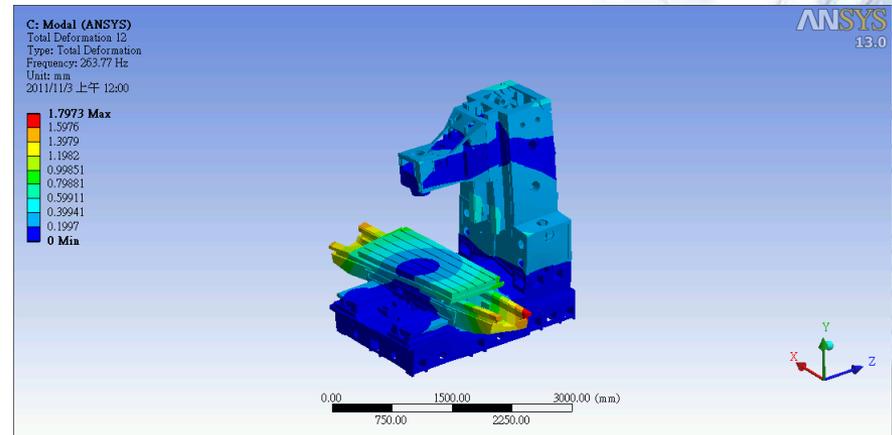
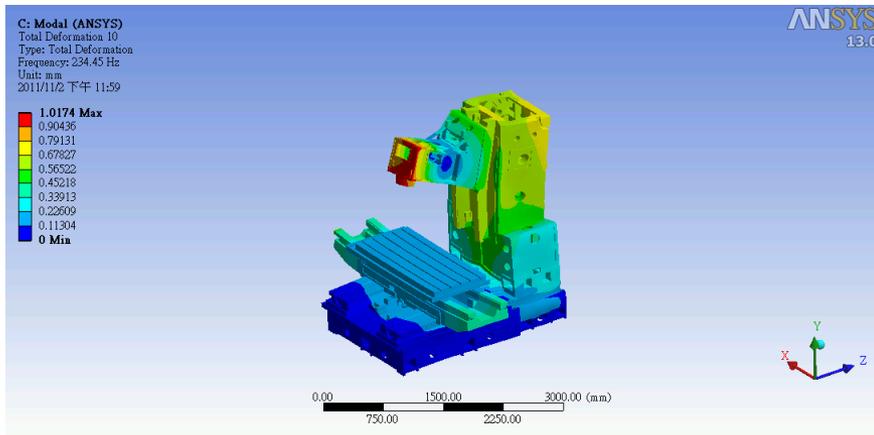
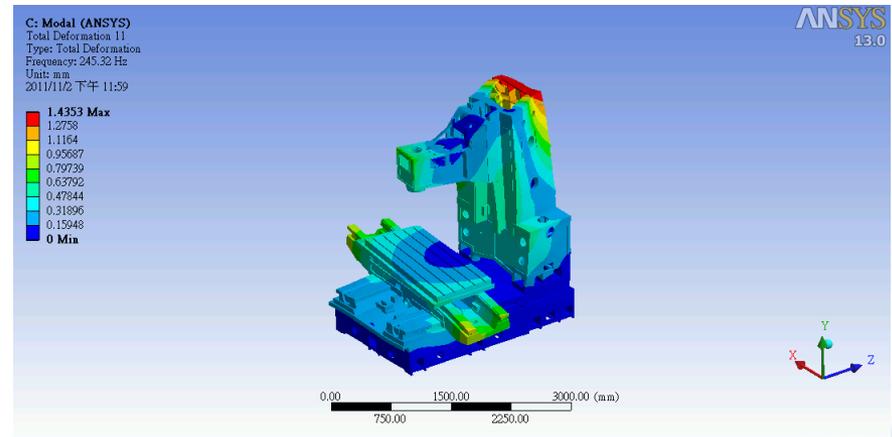
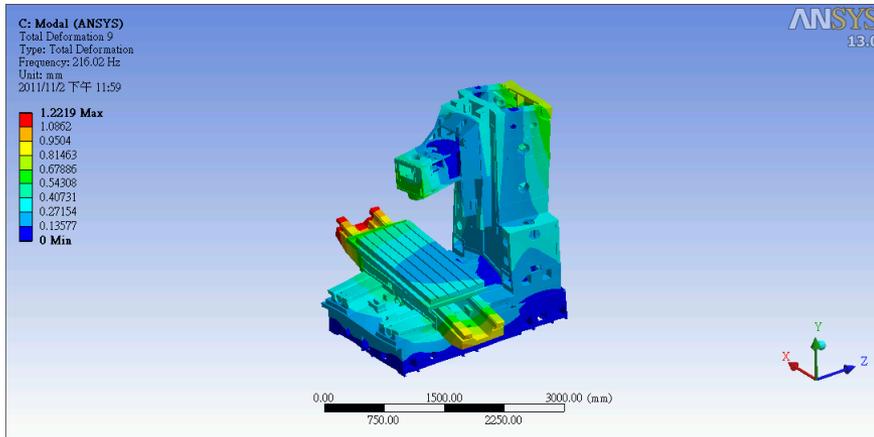


動態系統實驗室



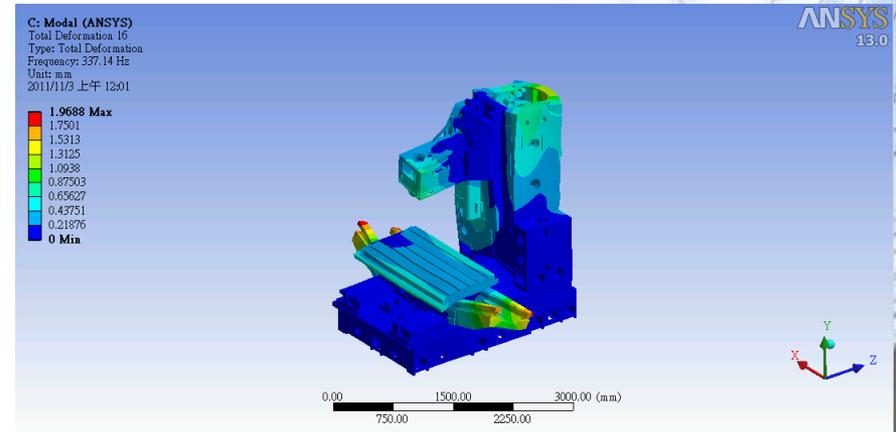
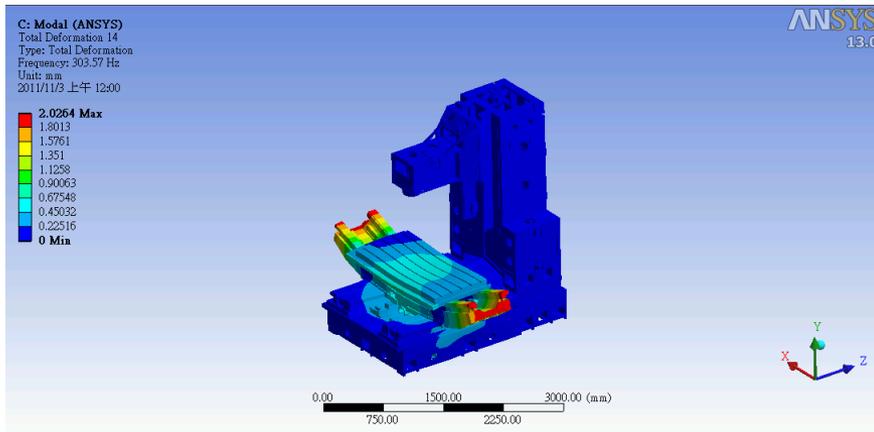
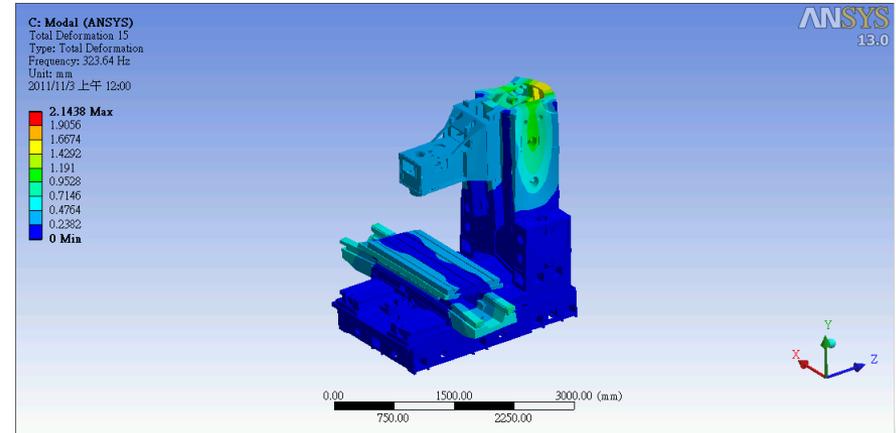
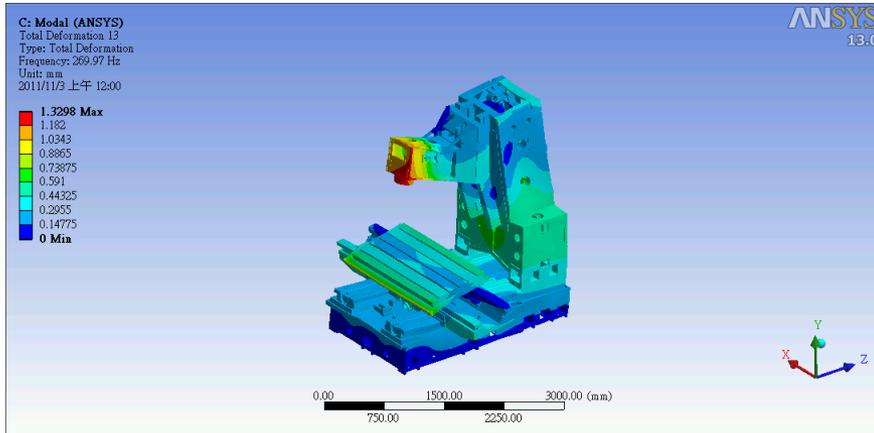


動態系統實驗室



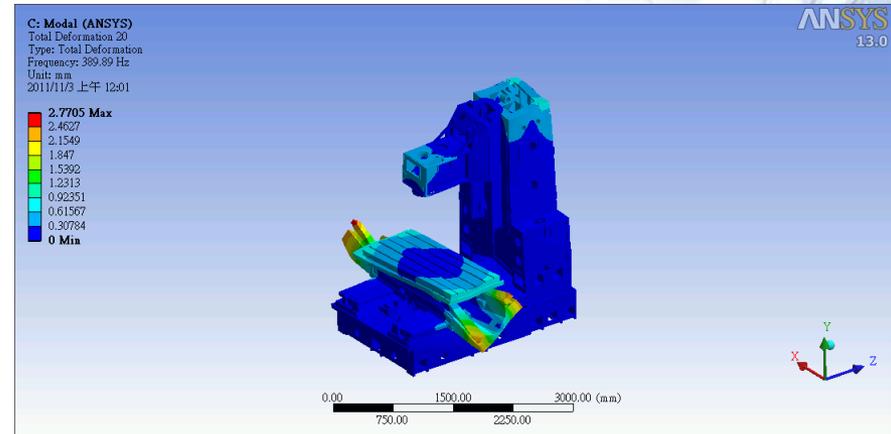
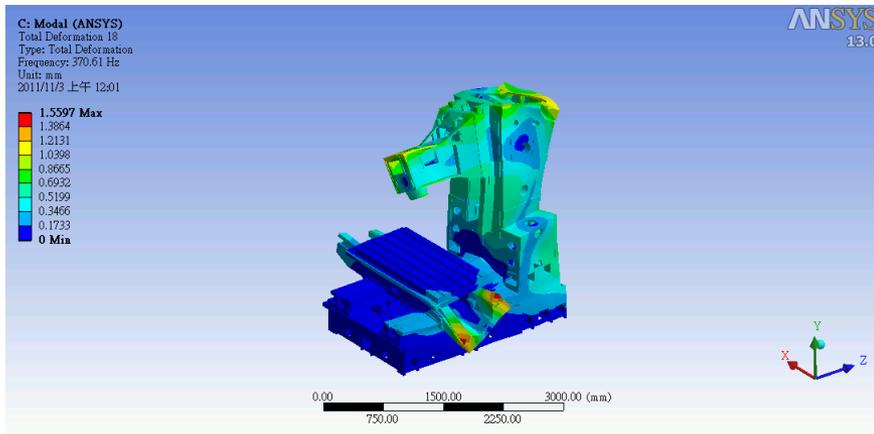
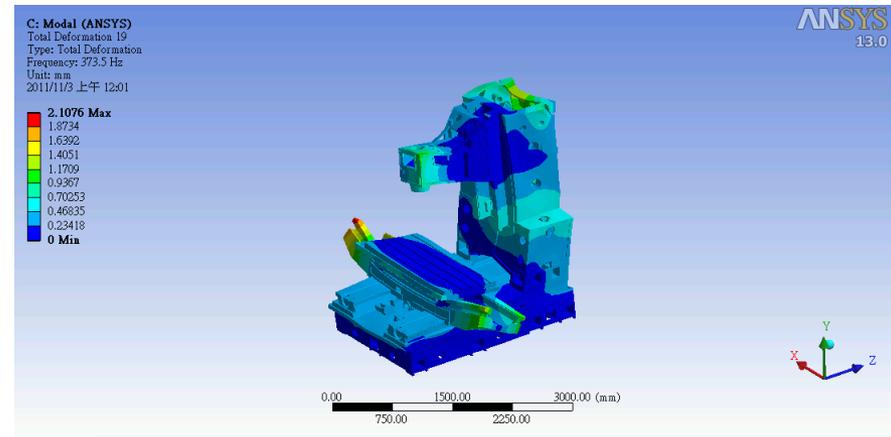
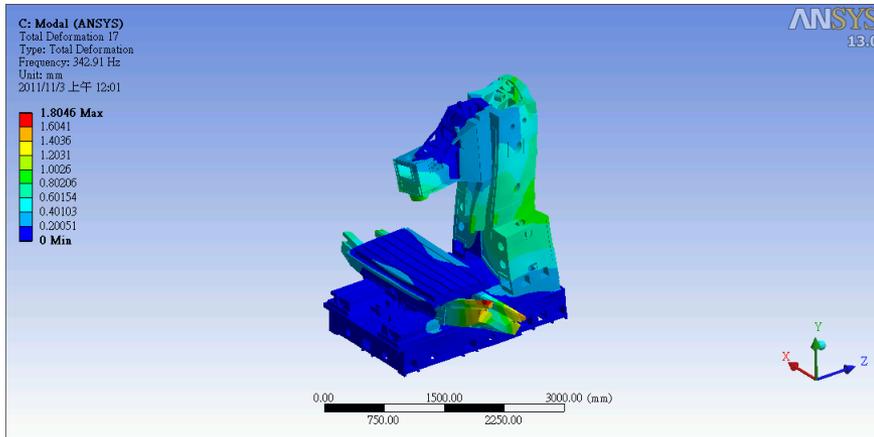


動態系統實驗室





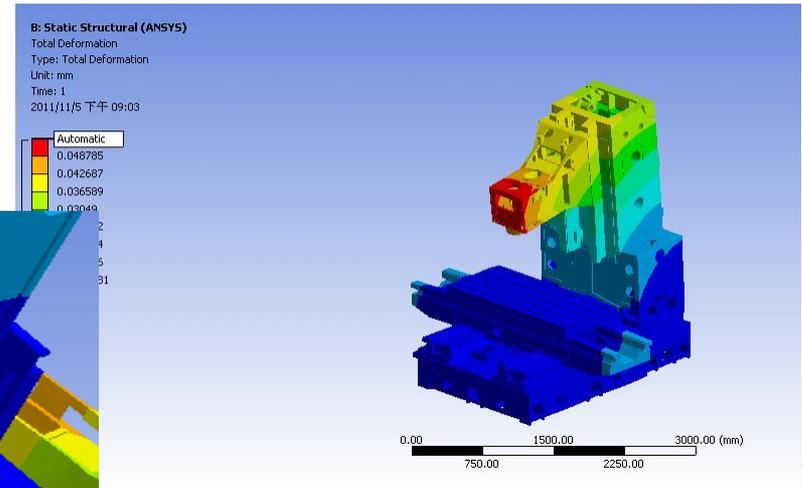
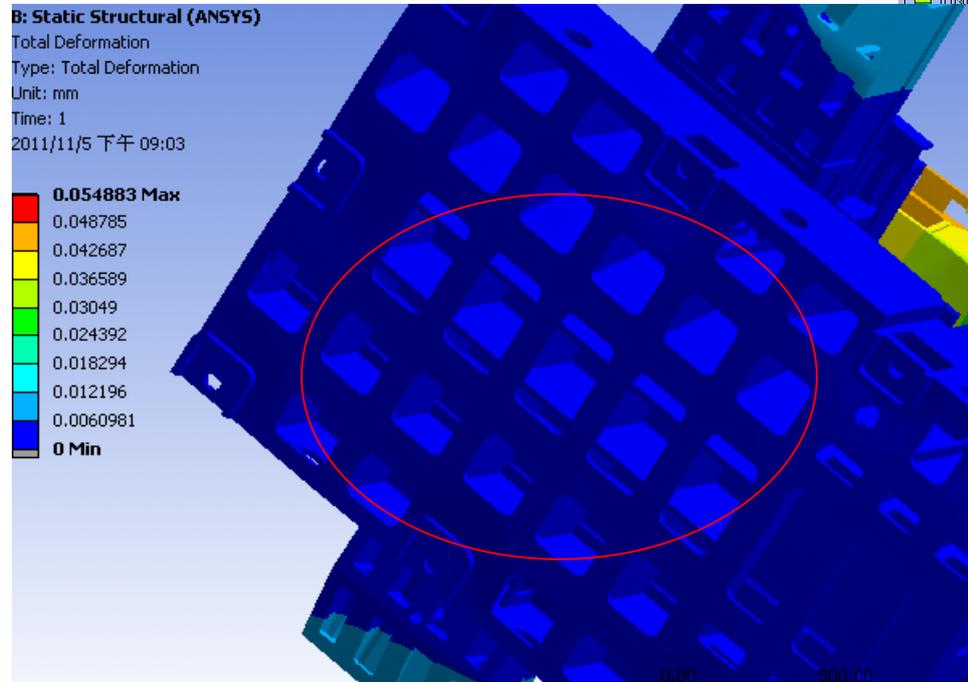
動態系統實驗室





動態系統實驗室

改善設計\_十字肋結構

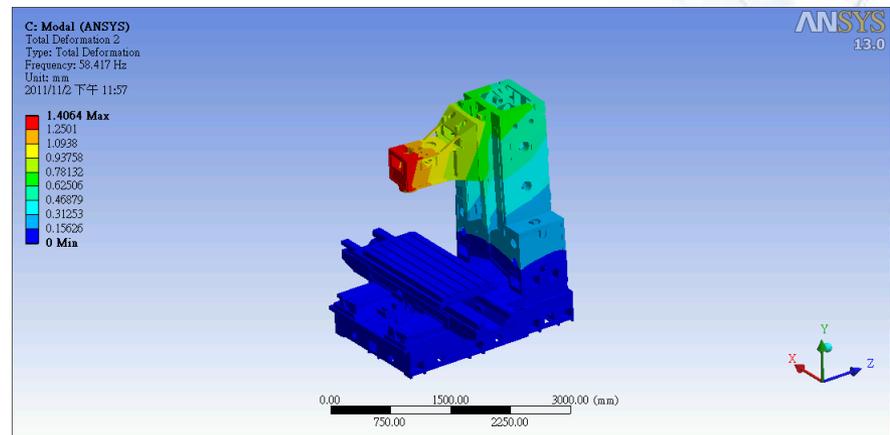
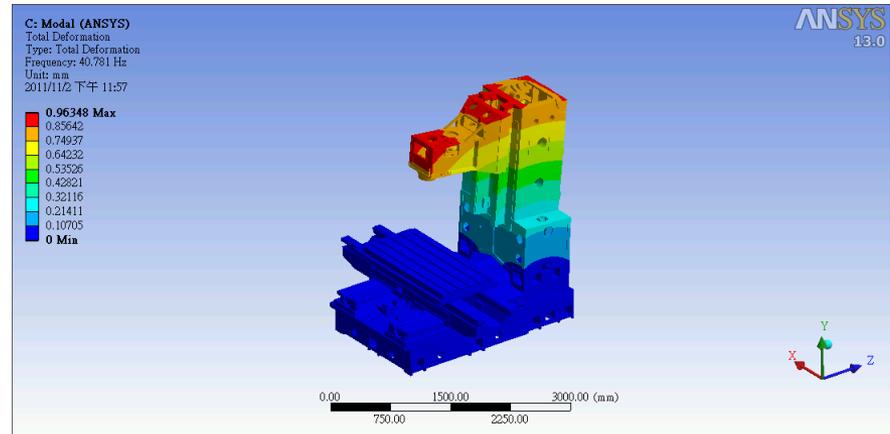




動態系統實驗室

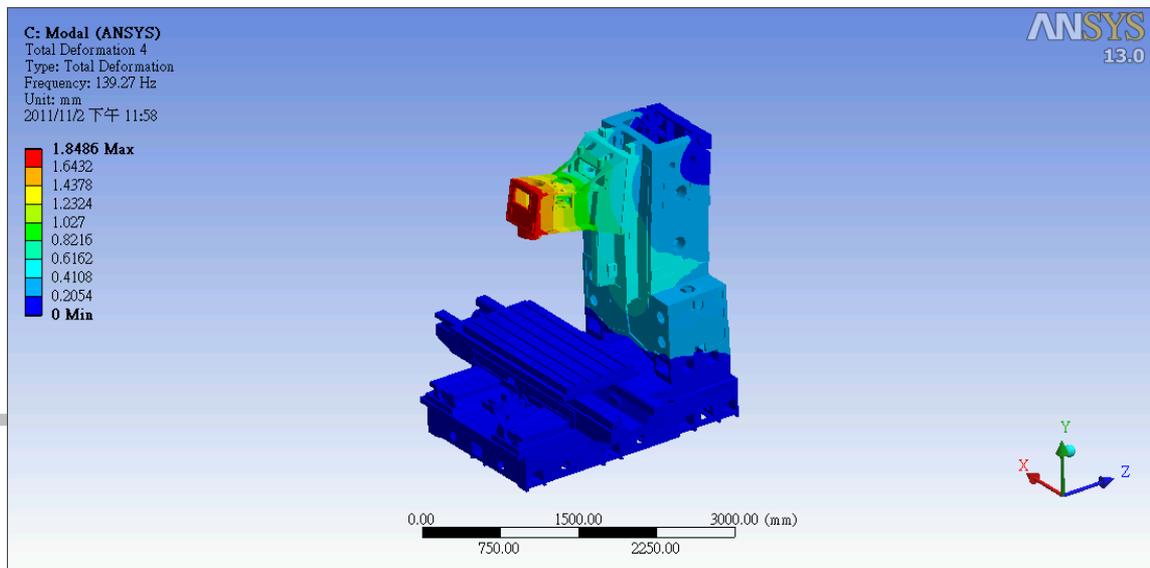
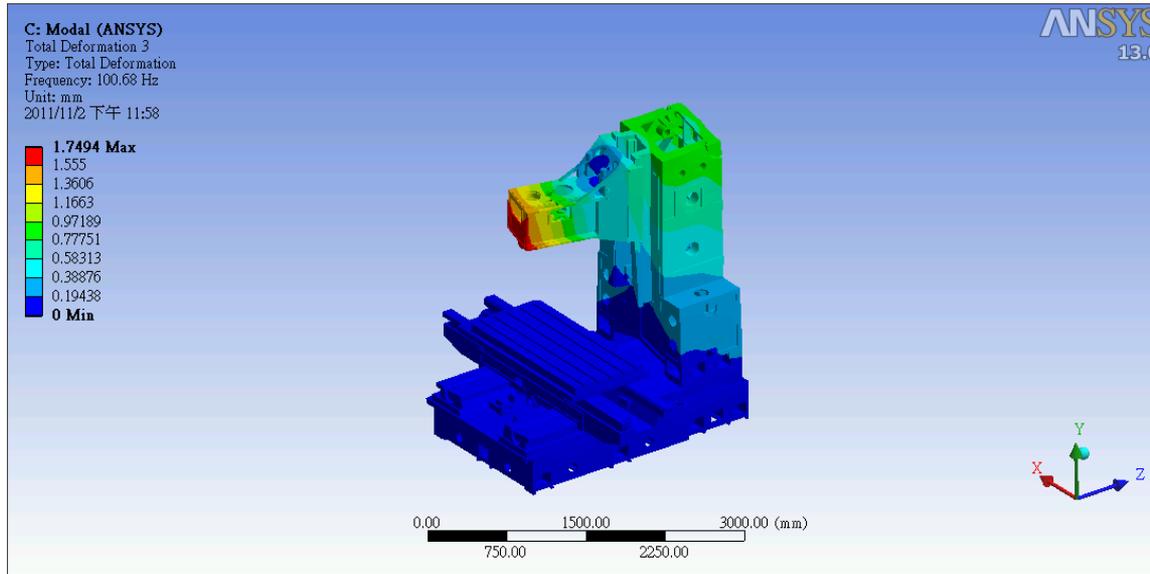
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4	4.	141.5
5	5.	184.42
6	6.	200.97
7	7.	203.55
8	8.	233.19
9	9.	238.35
10	10.	260.75
11	11.	271.66
12	12.	285.72
13	13.	289.5
14	14.	327.33
15	15.	338.42
16	16.	345.54
17	17.	351.92
18	18.	372.23
19	19.	392.73
20	20.	394.62

	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
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2	2.	38.249
3	3.	65.966
4	4.	92.165
5	5.	120.12
6	6.	130.9
7	7.	132.58
8	8.	151.89
9	9.	155.25
10	10.	169.83
11	11.	176.94
12	12.	186.1
13	13.	188.56
14	14.	213.2
15	15.	220.43
16	16.	225.06
17	17.	229.22
18	18.	242.45
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20	20.	257.03



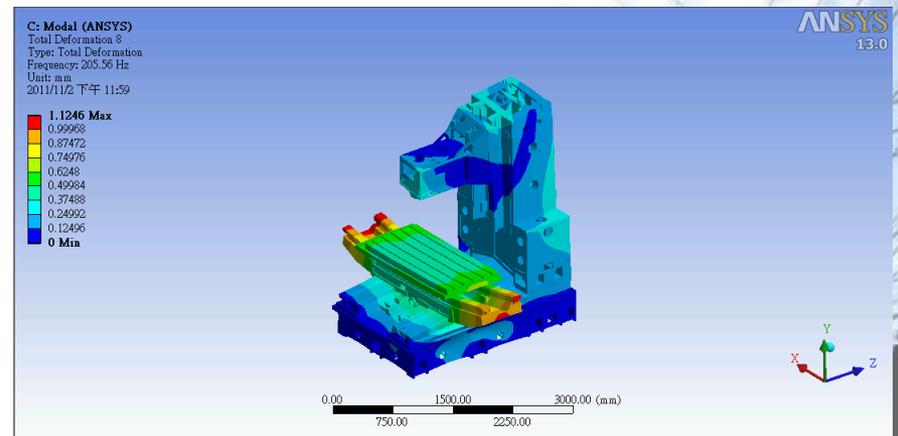
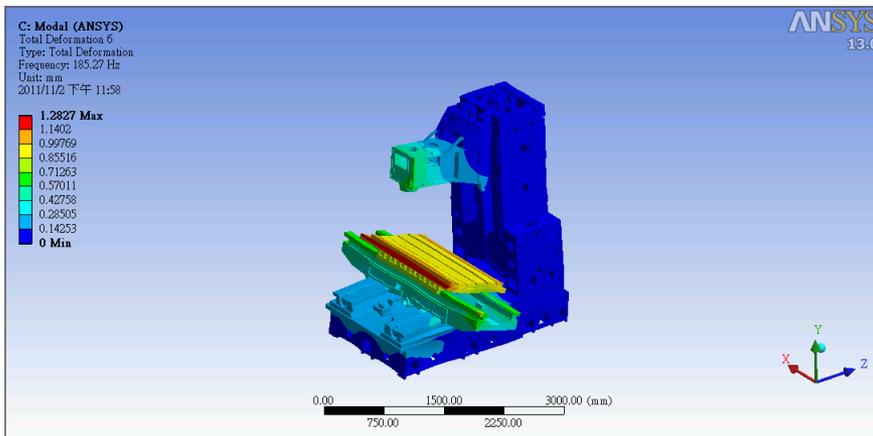
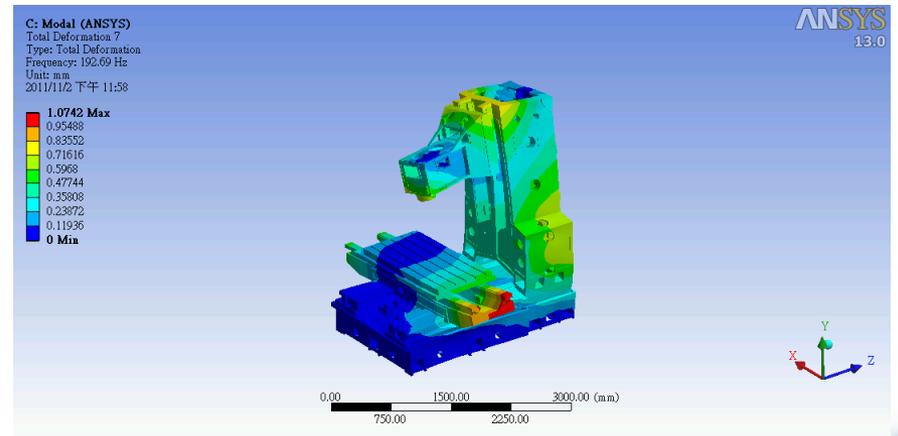
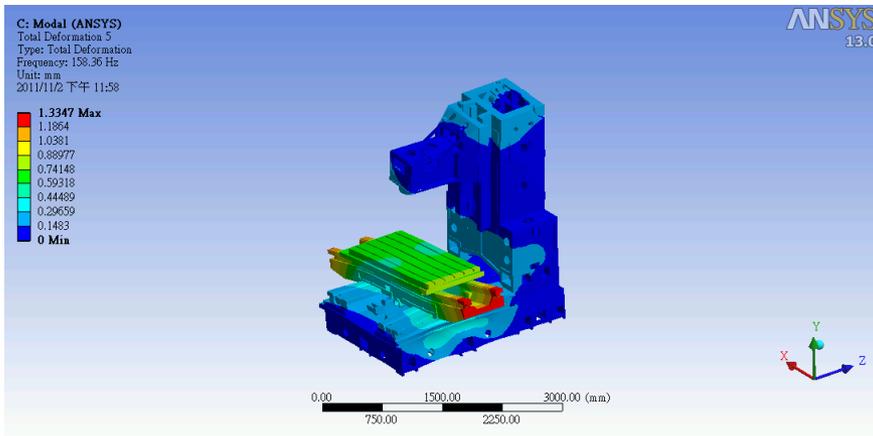


動態系統實驗室



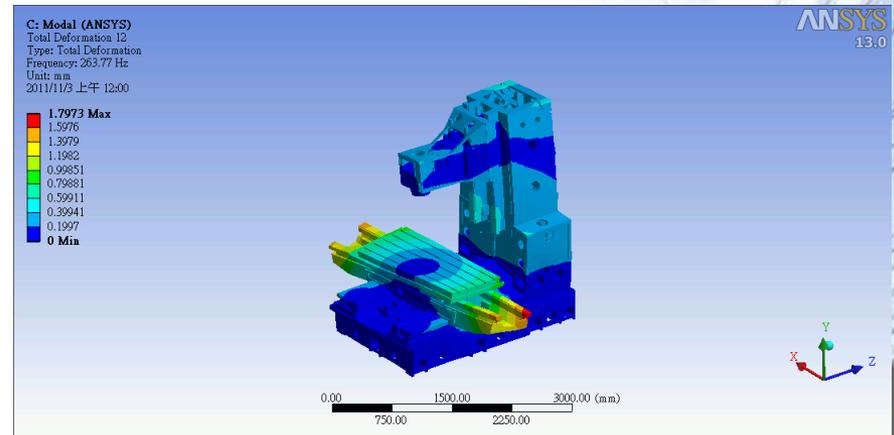
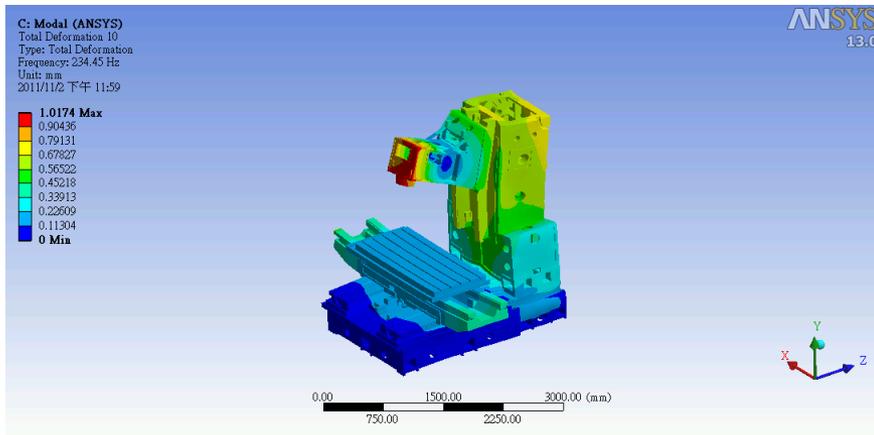
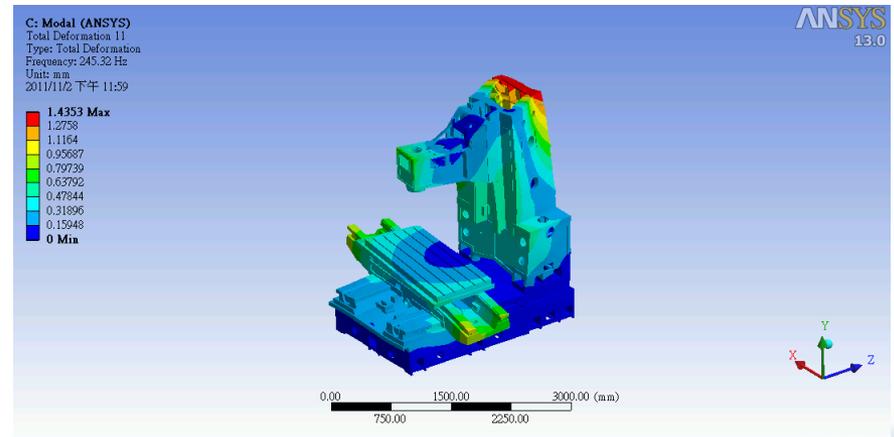
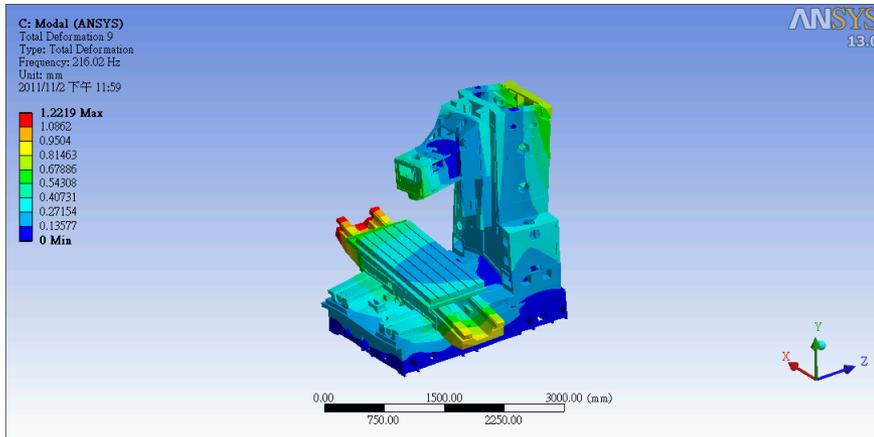


動態系統實驗室



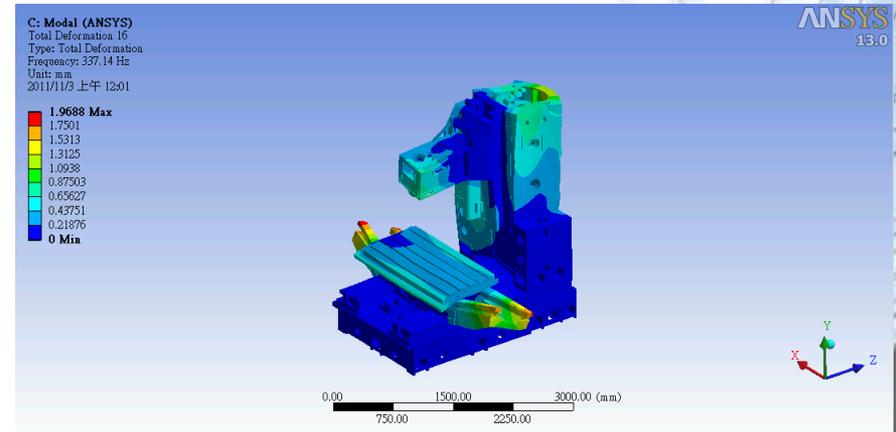
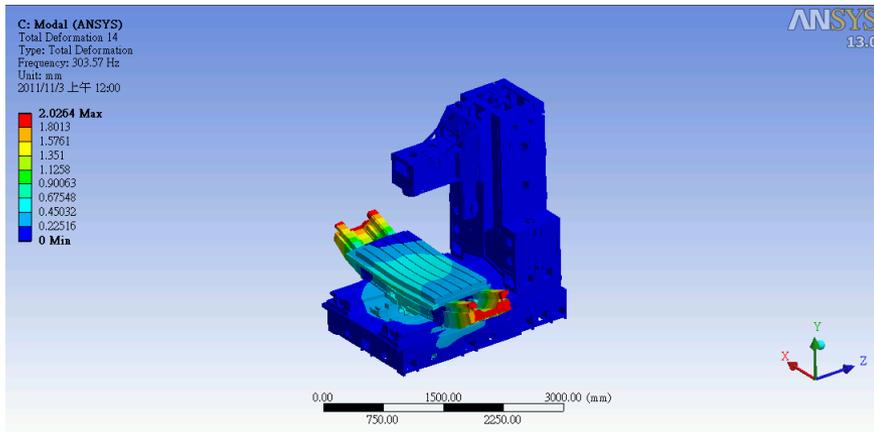
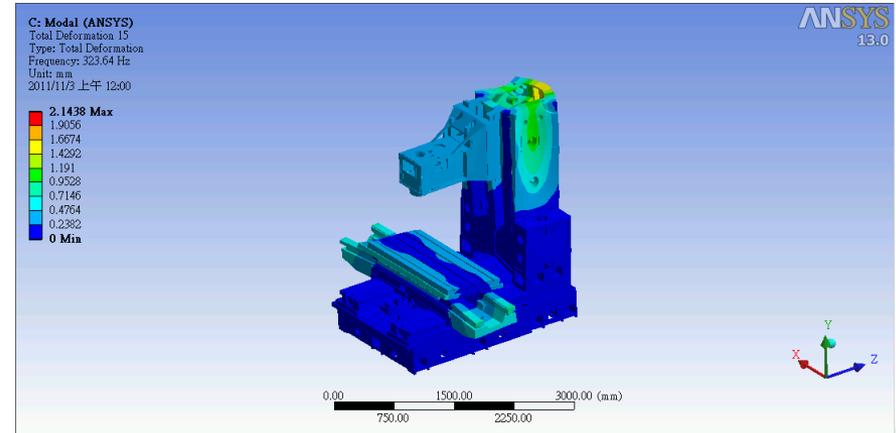
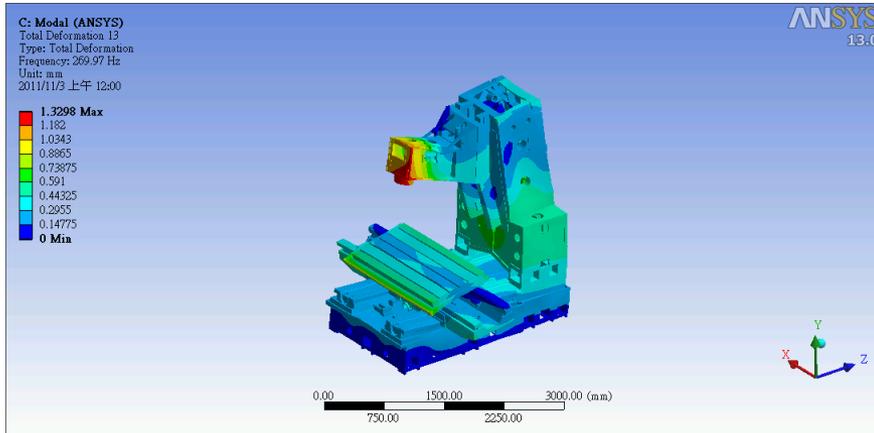


動態系統實驗室



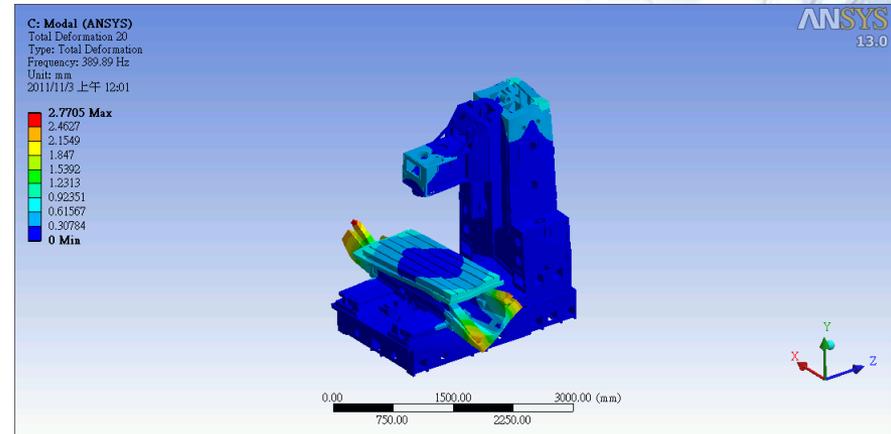
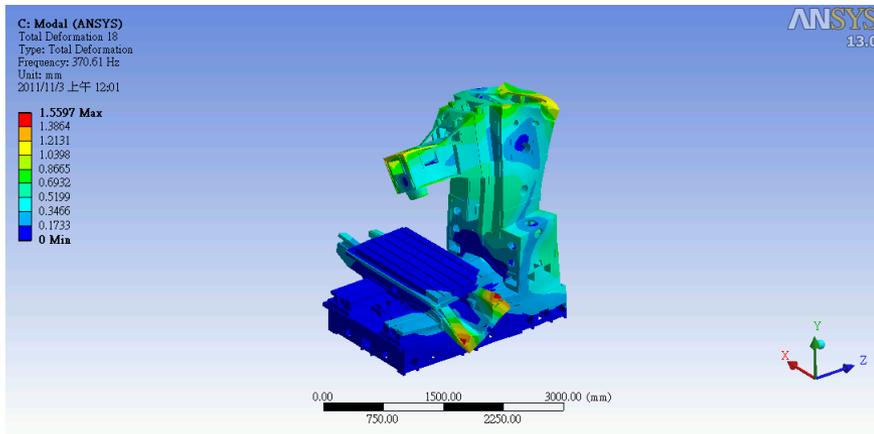
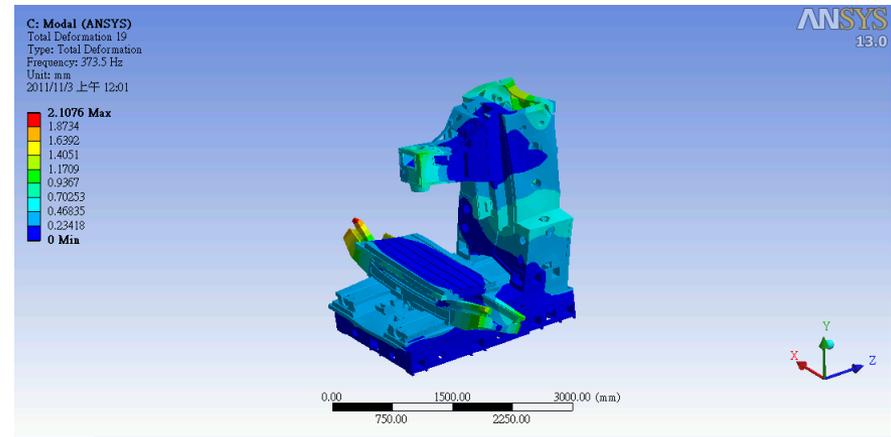
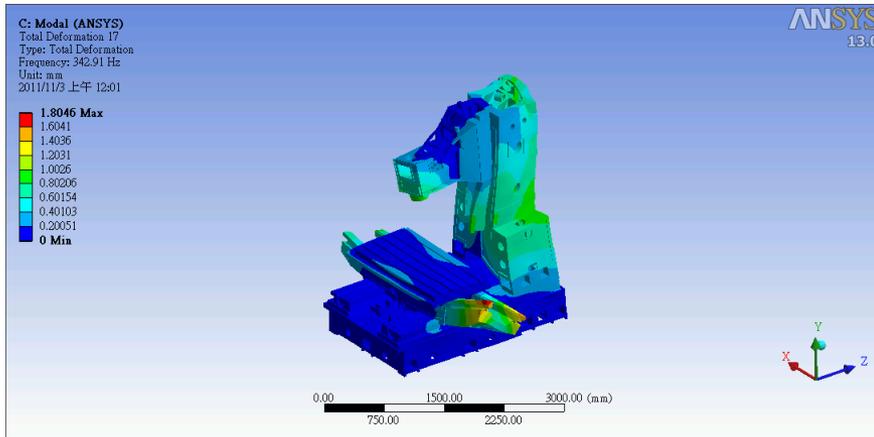


動態系統實驗室





動態系統實驗室





# 拓樸最佳化運用於工具機動態 結構之分析與應用





# 結構輕量化設計

在結構靜態的輕量化設計方面，一般採用的目標函數有三種，即為結構順從度、結構剛性、結構特徵值，目前主要多以提高結構剛性為主，或以降低結構的順從度為目標，其數學模型式為

$$\text{Minimize} \quad \phi = \sum_{i=1}^M f_i u_i = \{F\}^T \{U\}$$

$$\text{Subject to} \quad G = \sum_{i=1}^n \rho_i v_i \leq V$$

$$0 \leq \rho_i \leq 1$$

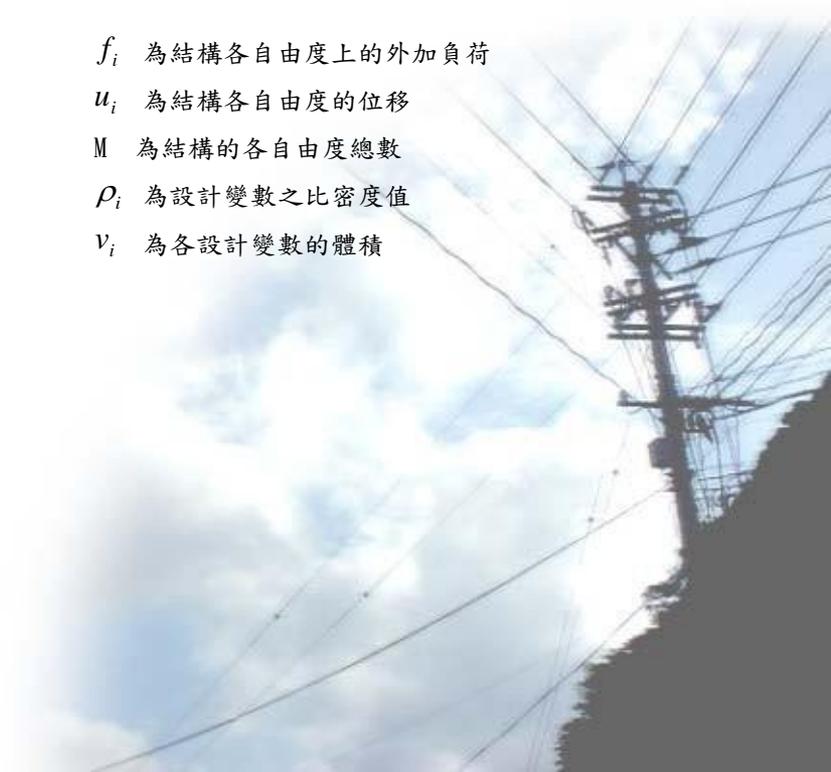
$f_i$  為結構各自由度上的外加負荷

$u_i$  為結構各自由度的位移

$M$  為結構的各自由度總數

$\rho_i$  為設計變數之比密度值

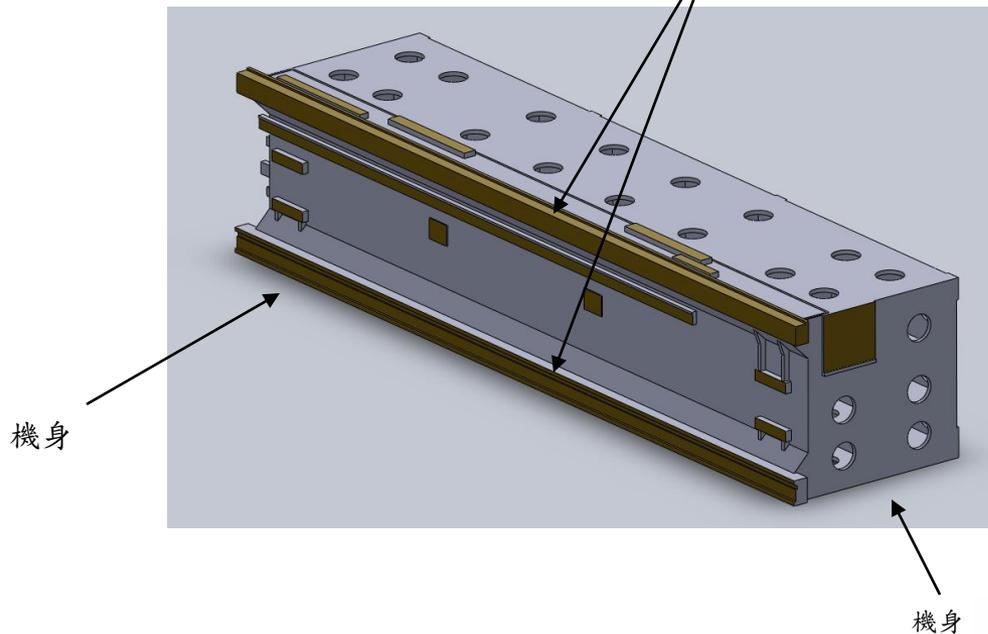
$v_i$  為各設計變數的體積





# 工具機橫樑最佳化設計

圖為一龍門型工具機橫樑主結構，底部須與機身相連固定，而線軌承接面必須考慮主軸頭質量負載以及自身質量。



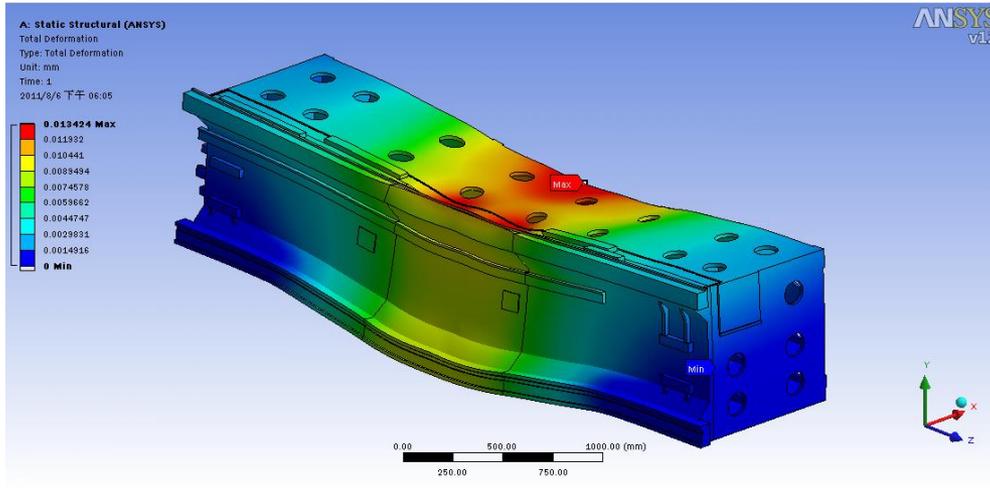
在拓樸最佳化之前必須先進行結構分析確認結構剛性是否足夠，如果不足，則須加強結構剛性





動態系統實驗室

# 工具機橫樑最佳化設計



材料	ASTM A572 Grad055
橫樑結構質量(Kg)	3995.6
主軸頭整體質量(Kg)	2063.3
最大變形量(mm)	0.01342

橫樑的原始設計上承受自身質量及主軸頭質量下變形量約0.01342 mm，結構剛性足夠，故針對此設計再進一步進行拓樸最佳化分析。

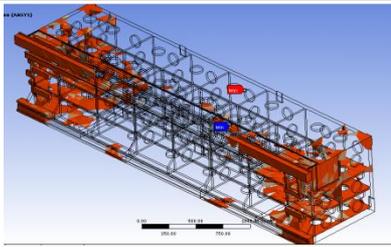
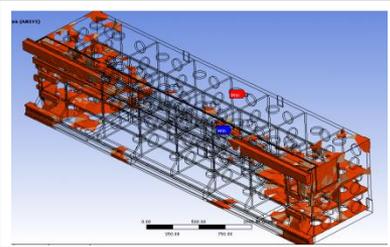
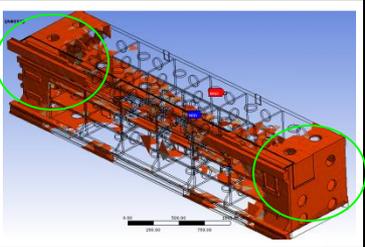
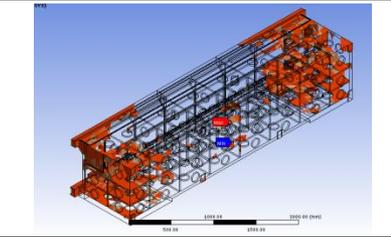
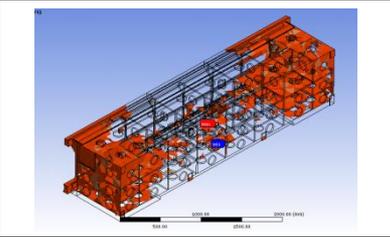
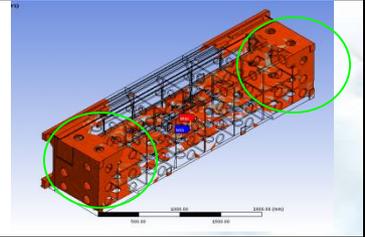


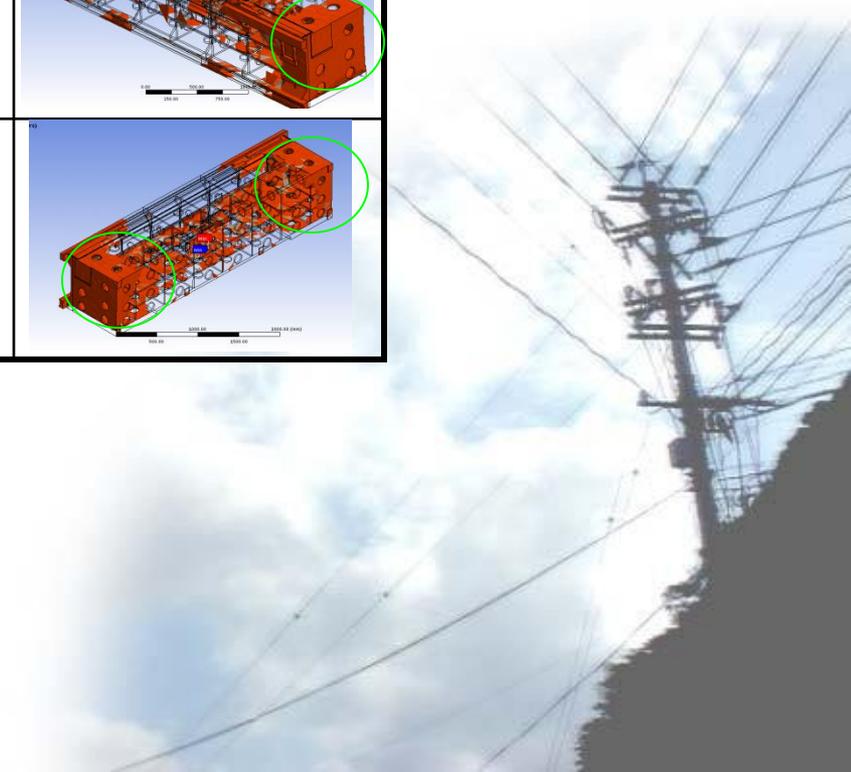


動態系統實驗室

# 拓樸最佳化分析

在不考慮製造及加工的情況下，針對原始設計進行減重區域界定，如表所示。

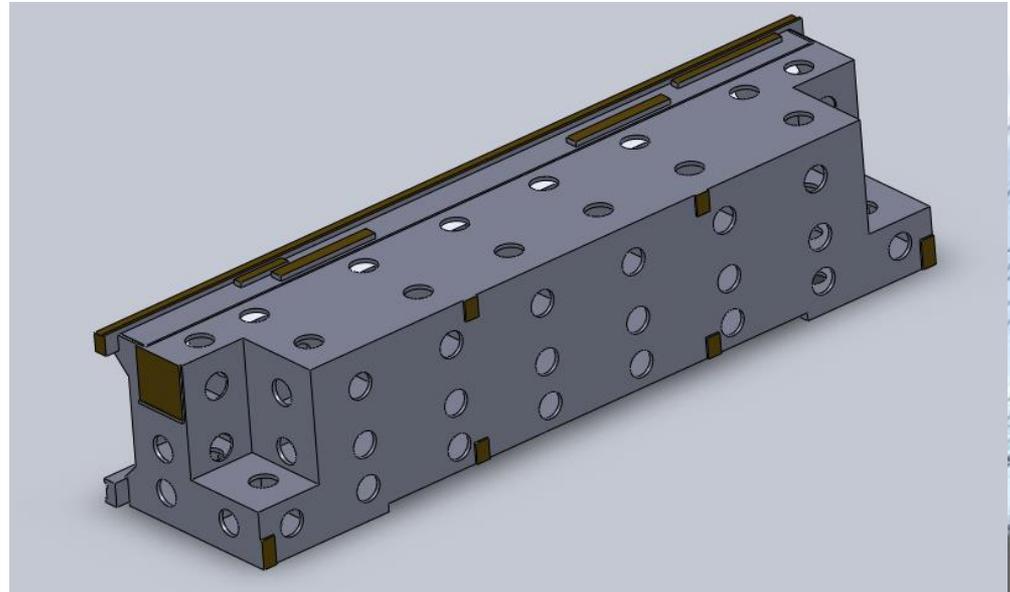
減重%	10%	20%	30%
正面			
背面			



## 拓樸最佳化分析改善方案

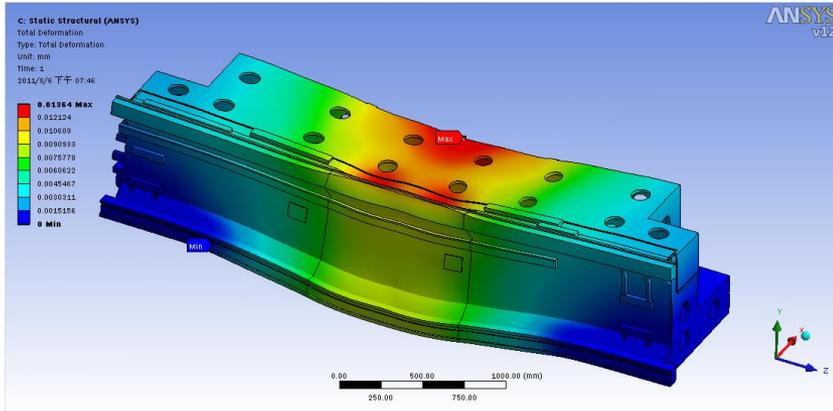
橫樑的兩側有明顯的減重空間，但線軌承載面不能夠列入減重區域，而兩側底部須與機身做接合面，底部部分不建議列入減重範圍內

材料	ASTM A572 Grad055
橫樑質量(Kg)	3797.5
主軸頭質量(Kg)	2063.3
最大變形量(mm)	0.01364





# 拓樸最佳化分析改善方案



	原始設計	改善設計
變形量(mm)	0.01342	0.01364
質量(kg)	3995.6	3797.5
等效應力MPa	3.557	3.755
等效應變	1.7e-5	1.8e-5
第一模態(Hz)	215	210
第二模態(Hz)	247	246
第三模態(Hz)	357	350
第四模態(Hz)	360	352
第五模態(Hz)	394	401
第六模態(Hz)	506	511

經過改善設計後，其結構強度分析如圖所示，可明顯看出質量下降許多，如表所示，減少約198.1KG，但整體靜剛性和動剛性並沒有相差許多，減少的重量依據目前市價可減少約1萬元成本左右，但只對外型做改善，若能再針對肋材部分加以改善，相信能再減少更多結構質量。



動態系統實驗室

# 拓樸最佳化分析

若不能更動外型設計只能更動砂心的情況下，故改善方案二只能針對肋厚的部分進行改善。

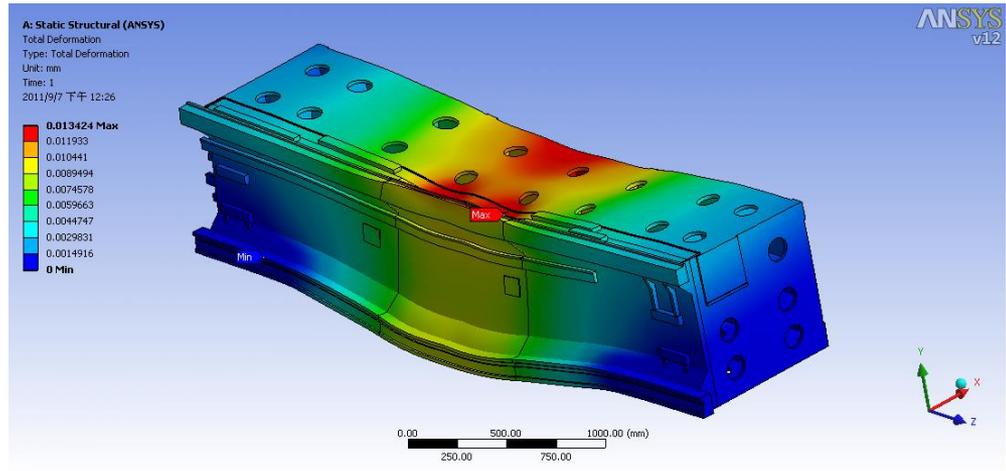
	10%	20%	30%
第一層肋			
第二層肋			
第三層肋			

從上表的拓樸圖形得知，中後排的肋厚都有可以減重的空間，但會受限於整體外型設計不得更動。

# 拓樸最佳化分析改善方案

藉由拓樸最佳化所得出之拓樸圖形，將部份肋材厚度從19 mm 改成16 mm，在整體外型不能更動下，其結構分析結果如下圖和下表所示

	原始設計	改善設計
變形量(mm)	0.01342	0.013424
質量(kg)	3995.6	3806.7
等效應力MPa	3.557	3.5539
等效應變	1.7e-5	1.77e-5
第一模態(Hz)	215	213
第二模態(Hz)	247	251
第三模態(Hz)	357	356
第四模態(Hz)	360	359
第五模態(Hz)	394	402
第六模態(Hz)	506	505



減少的質量約188.9 KG



## 結論

在結構輕量化時，可由拓樸最佳化所得到的拓樸圖形去得知，需要加強結構的剛性和減少材料的使用量的位置，讓整體材料能夠均勻的使用，不會產生過度的浪費而增加成本，對於工具機幾個主要移動件諸如橫樑、立柱、主軸頭、床鞍等，若能在設計前給予輕量化之設計，對工具機高速進給時，因為慣性力所產生之振動，能夠大幅的減少，另外也可減少伺服馬達的耗能外，更能進而提高精度，滑軌也會因重量減少而增長使用壽命。