

工學碩士 學位論文

**A Study on the Vibration Analysis of a Power Transmission
Converter by Sub-structure Synthesis Method**

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2000 2

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Abstract

This study intends to improve the machinery properties by reducing the weight of the converter without changing the dynamic characteristics.

At first, the Vibration analyses by the Substructure Synthesis Method and by F.E.A using the ANSYS are performed for the converter model to confirm the reliability of the analyzing tools. Weight minimization is performed by the Sensitivity Analysis and the Optimum Structural Modification.

To decrease the converter weight ideally, the weight parts with low sensitivity is to be cut mainly, and the changing quantity of the natural frequency by the cut is to be recovered by the weight modification of the parts with high sensitivity.

Mathematically unique solution for the homogeneous problem(i. e. 0 object function problem) does not exist, then the converter is redesigned with much thinner initial thickness, The natural frequencies and natural modes of original structure by the sensitivity analysis, and then observed the Frequency Response Functions(FRF) are observed for some interesting points.

In this analysis, the original thickness of the converter model is 84 mm, and the redesigned initial thickness is 60 mm and 70 mm. And the numbers of the interesting natural frequencies are 1, 2, 4 respectively.

The results are as follows :

- (1) The weight for the each case could be reduced without changing the objective natural frequencies.
- (2) According to the exciting frequency range of the converter, effective weight minimization is possible. For the case of narrow frequency band, weight reduction effect is higher than that of wide frequency band's.

- (3) The method could be applied not only for the weight minimization, but also for the improvement of dynamic characteristics of the converter.

$[A]$	(sensitivity matrix)
$\{F\}$	
$\{I\}$	
$[K]$	
$[K']$	
$[M]$	
$[M']$	
$[T]$	
$\{X\}$	
c	
e	
$\{r\}$	
γ	
$\Delta\gamma$	
λ	
λ_r	r
λ_r'	r
$\{\xi\}$	
$\{\phi_r\}$	r
$\{\phi_r'\}$	r
$[\phi]$	

ω_r r

ω_r' r

[]

[U]

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1.

가 .

, 가

가 가 .

()

, , .

, .

가 .

(Weight minimization)[12] [13]

가

, 가

,

method)[14] [17]

(Sub-structure synthesis

, ,

.

(Sensitivity Analysis Method)[1] [7]

,

(Optimum structural

modification method)[8] [11]

.

가 ,

가 .

, ([A] {Δγ} = {Δω}), (

) (Non-trivial

solution)

.

1 가 가

가

가

ANSYS

가 가

가 가

가

(

가

가

가

가

가 가

2.

가 가 가
가
()
()
(Transfer function synthesis method),
(Characteristic matrix synthesis method), (Component mode synthesis
method ; CMS)

가

가

Guyan

가

2.1 (Guyan's static reduction)

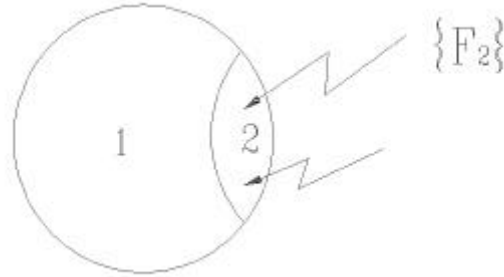


Fig. 2.1 Guyan's reduction model

Fig. 2.1

$$\left(-\omega^2 \begin{bmatrix} \mathbf{M}_{11} & \mathbf{M}_{12} \\ \mathbf{M}_{21} & \mathbf{M}_{22} \end{bmatrix} + \begin{bmatrix} \mathbf{K}_{11} & \mathbf{K}_{12} \\ \mathbf{K}_{21} & \mathbf{K}_{22} \end{bmatrix} \right) \begin{Bmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \end{Bmatrix} = \begin{Bmatrix} \mathbf{0} \\ \mathbf{F}_2 \end{Bmatrix} \quad (2-1)$$

$$\begin{bmatrix} \mathbf{K}_{11} & \mathbf{K}_{12} \\ \mathbf{K}_{21} & \mathbf{K}_{22} \end{bmatrix} \begin{Bmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \end{Bmatrix} = \begin{Bmatrix} \mathbf{0} \\ \mathbf{F}_2 \end{Bmatrix} \quad (2-2)$$

가 . $\{\mathbf{X}_1\}$,

$$[\mathbf{K}_{11}] \{\mathbf{X}_1\} + [\mathbf{K}_{12}] \{\mathbf{X}_2\} = \{\mathbf{0}\}$$

$$\{\mathbf{X}_1\} = [\mathbf{T}] \{\mathbf{X}_2\} \quad (2-3)$$

, $[\mathbf{T}]$ Guyan [18] .

$$[\mathbf{T}] = -[\mathbf{K}_{11}]^{-1} [\mathbf{K}_{12}] \quad (2-4)$$

$$\begin{Bmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \end{Bmatrix} = \begin{bmatrix} [\mathbf{T}] \\ \mathbf{I} \end{bmatrix} \{\mathbf{X}_2\} \quad (2-5)$$

$$(2-5) \quad (2-1) \quad [[\mathbf{T}]^T \mathbf{I}] \quad ,$$

$$- \omega^2 [\tilde{\mathbf{M}}] \{\mathbf{X}_2\} + [\tilde{\mathbf{K}}] \{\mathbf{X}_2\} = \{\mathbf{F}_2\} \quad (2-6)$$

$$[\tilde{\mathbf{M}}] = [\mathbf{T}]^T [\mathbf{M}_{11}] [\mathbf{T}] + [\mathbf{T}]^T [\mathbf{M}_{12}] + [\mathbf{M}_{21}] [\mathbf{T}] + [\mathbf{M}_{22}]$$

$$[\tilde{\mathbf{K}}] = [\mathbf{T}]^T [\mathbf{K}_{11}] [\mathbf{T}] + [\mathbf{T}]^T [\mathbf{K}_{12}] + [\mathbf{K}_{21}] [\mathbf{T}] + [\mathbf{K}_{22}] \quad (2-7)$$

2.2

Guyan

가

(2-1)

가

가

Fig. 2-2

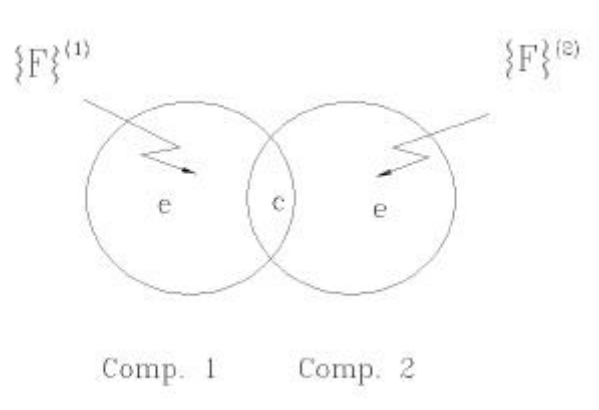


Fig. 2.2 Rigid jointed model

Fig. 2.2

c

e

$$\left(-\omega^2 \begin{bmatrix} M_{ee}^{(1)} & M_{ec}^{(1)} & 0 & 0 \\ M_{ce}^{(1)} & M_{cc}^{(1)} & 0 & 0 \\ 0 & 0 & M_{ee}^{(2)} & M_{ec}^{(2)} \\ 0 & 0 & M_{ce}^{(2)} & M_{cc}^{(2)} \end{bmatrix} + \begin{bmatrix} K_{ee}^{(1)} & K_{ec}^{(1)} & 0 & 0 \\ K_{ce}^{(1)} & K_{cc}^{(1)} & 0 & 0 \\ 0 & 0 & K_{ee}^{(2)} & K_{ec}^{(2)} \\ 0 & 0 & K_{ce}^{(2)} & K_{cc}^{(2)} \end{bmatrix} \right) \begin{Bmatrix} X_e^{(1)} \\ X_c^{(1)} \\ X_e^{(2)} \\ X_c^{(2)} \end{Bmatrix} = \begin{Bmatrix} F_e^{(1)} \\ F_c + F_r^{(1)} \\ F_e^{(2)} \\ F_r^{(2)} \end{Bmatrix} \quad (2-8)$$

가 ,

$F_r^{(1)}$ c

1 2

(2-8)

$$-\omega^2 [\mathbf{M}] \{\mathbf{X}\} + [\mathbf{K}] \{\mathbf{X}\} = \{\mathbf{F}\} \quad (2-9)$$

$$\{\mathbf{X}_c\} = \{\mathbf{X}_c^{(1)}\} = \{\mathbf{X}_c^{(2)}\} \quad (2-10)$$

$$\{\mathbf{F}_r\} = -\{\mathbf{F}_r^{(1)}\} = \{\mathbf{F}_r^{(2)}\} \quad (2-11)$$

Guyan [T]

$$\{\mathbf{X}_c\} = [\mathbf{T}] \{\mathbf{X}_c\} \quad (2-12)$$

$$\{\mathbf{X}_c\} = [\mathbf{T}] \{\mathbf{X}_c\} + [\Phi] \{\hat{\xi}\} \quad (2-13)$$

$$[\Phi] \quad [T]$$

[Φ] 가

$$(2-13) \quad (2-8)$$

$$\begin{aligned}
\{X\} &= \begin{Bmatrix} X_e^1 \\ X_c^1 \\ X_e^2 \\ X_c^2 \end{Bmatrix} = \begin{bmatrix} \Phi^1 & T^1 & 0 & 0 \\ 0 & I & 0 & 0 \\ 0 & 0 & \Phi^2 & T^2 \\ 0 & 0 & 0 & I \end{bmatrix} \begin{Bmatrix} \xi^1 \\ X_c^1 \\ \xi^2 \\ X_c^2 \end{Bmatrix} \\
&= \begin{bmatrix} \Phi^1 & T^1 & 0 \\ 0 & I & 0 \\ 0 & T^2 & \Phi^2 \\ 0 & I & 0 \end{bmatrix} \begin{Bmatrix} \xi^1 \\ X_c \\ \xi^2 \end{Bmatrix} \\
&= [T_p] \{Y\} \tag{2-14}
\end{aligned}$$

,

$$[T_p] = \begin{bmatrix} \Phi^1 & T^1 & 0 \\ 0 & I & 0 \\ 0 & T^2 & \Phi^2 \\ 0 & I & 0 \end{bmatrix} \tag{2-15}$$

$$\{Y\} = \begin{Bmatrix} \xi^1 \\ X_c \\ \xi^2 \end{Bmatrix} \tag{2-16}$$

가 . (2-14) (2-9) , [T_p] ,

$$- \omega^2 [\tilde{M}] \{Y\} + [\tilde{K}] \{Y\} = \{\tilde{F}\} \tag{2-17}$$

,

$$[\tilde{M}] = [T_p]^T [M] [T_p] ,$$

$$[\tilde{K}] = [T_p]^T [K] [T_p] ,$$

$$\{\tilde{\mathbf{F}}\} = [\mathbf{T}_p] \{\mathbf{F}\} = \begin{Bmatrix} [\boldsymbol{\Phi}^1]^T \{\mathbf{F}_e^1\} \\ [\mathbf{T}^1]^T \{\mathbf{F}_e^1\} + [\mathbf{T}^2]^T \{\mathbf{F}_e^2\} \\ [\boldsymbol{\Phi}^2]^T \{\mathbf{F}_e^2\} \end{Bmatrix} \quad (2-18)$$

, (2-17)

(2-9) , (2-17)
가

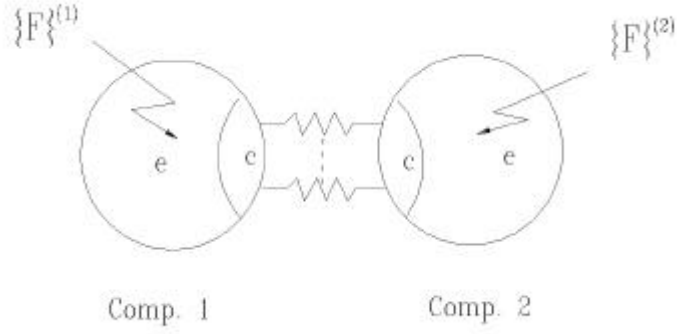


Fig. 2.3 Spring jointed model

Fig. 2.3 가

$$\begin{bmatrix} K_{c11} & -K_{c12} \\ -K_{c21} & K_{c22} \end{bmatrix} \begin{Bmatrix} X_c^{(1)} \\ X_c^{(2)} \end{Bmatrix} = \begin{Bmatrix} -F_r^{(1)} \\ F_r^{(2)} \end{Bmatrix} \quad (2-19)$$

{F_r}

(2-8) 가 ,

$$\left(-\omega^2 \begin{bmatrix} M_{ee}^{(1)} & M_{ec}^{(1)} & 0 & 0 \\ M_{ce}^{(1)} & M_{cc}^{(1)} & 0 & 0 \\ 0 & 0 & M_{ee}^{(2)} & M_{ec}^{(2)} \\ 0 & 0 & M_{ce}^{(2)} & M_{cc}^{(2)} \end{bmatrix} + \begin{bmatrix} K_{ee}^{(1)} & K_{ec}^{(1)} & 0 & 0 \\ K_{ce}^{(1)} & K_{cc}^{(1)} + K_{c11} & 0 & -K_{c12} \\ 0 & 0 & K_{ee}^{(2)} & K_{ec}^{(2)} \\ 0 & -K_{c21} & M_{ce}^{(2)} & K_{cc}^{(2)} + K_{c22} \end{bmatrix} \right) \begin{Bmatrix} X_e^{(1)} \\ X_c^{(1)} \\ X_e^{(2)} \\ X_c^{(2)} \end{Bmatrix} = \begin{Bmatrix} F^{(1)} \\ F_c^{(1)} + F_r^{(1)} \\ F^{(2)} \\ F_c^{(2)} - F_r^{(1)} \end{Bmatrix} \quad (2-20)$$

가 , (2-14)가

$$\{X\} = \begin{Bmatrix} X_e^1 \\ X_c^1 \\ X_e^2 \\ X_c^2 \end{Bmatrix} = \begin{bmatrix} \Phi^1 & T^1 & 0 & 0 \\ 0 & I & 0 & 0 \\ 0 & 0 & \Phi^2 & T^2 \\ 0 & 0 & 0 & I \end{bmatrix} \begin{Bmatrix} \xi^1 \\ X_c^1 \\ \xi^2 \\ X_c^2 \end{Bmatrix} \equiv [T_p] \{Y\} \quad (2-21)$$

(2-20)

[T_p]^T

3.

가 , 가 ,
가 ,
가 ,
Fox
가
가 ,
가 ,
Fox
가

3.1 (Fox's sensitivity analysis method)

Fox [2]

$$\begin{aligned} (-\omega^2[M] + [K])\{X\} &= \{0\} \\ (-\lambda[M] + [K])\{X\} &= \{0\} \end{aligned} \quad (3-1)$$

r λ_r $\{\phi_r\}$,

$$\gamma \rightarrow \gamma_0 + \Delta\gamma$$

$$\gamma = \gamma_0 + \Delta\gamma \quad (3-2)$$

$[K]$, $[M]$, λ_r , ω_r , $\{\phi_r\}$ 1

$$\begin{aligned} [K] &= [K_0] + \frac{\partial[K]}{\partial\gamma} \cdot \Delta\gamma \\ &= [K_0] + [K'] \Delta\gamma \end{aligned}$$

$$[M] = [M_0] + [M'] \Delta\gamma$$

$$\omega_r = \omega_{0r} + \omega_r' \Delta\gamma \quad (3-3)$$

$$\lambda_r = \lambda_{0r} + \lambda_r' \Delta\gamma$$

$$\{\phi_r\} = \{\phi_{0r}\} + \{\phi_r'\} \Delta\gamma$$

$$, \lambda_r = \omega_r^2$$

$$\lambda' = 2\omega_{or} \omega_r' \qquad \omega_r' = \lambda_r' / 2 \omega_{or} \qquad (3-4)$$

$$\mathbf{r} \quad \lambda_{0r} \quad \lambda = \lambda_0$$

$$(-\lambda_{0r}[\mathbf{M}_0] + [\mathbf{K}_0])\{\phi_{0r}\} = \{0\} \quad (3-5)$$

$$(-\lambda_r[\mathbf{M}] + [\mathbf{K}])\{\phi_r\} = \{0\} \quad (3-6)$$

$$\cdot (3-6) \quad (3-3) \quad \Delta\gamma^2$$

$$\Delta\gamma \quad ,$$

$$(-\lambda_{0r}[\mathbf{M}_0] + [\mathbf{K}_0])\{\phi_r'\} = (\lambda_{0r}[\mathbf{M}'] + \lambda_r'[\mathbf{M}_0] - [\mathbf{K}'])\{\phi_{0r}\} \quad (3-7)$$

$$\cdot (3-7) \quad \{\phi_{0r}\}^T \quad , \quad 0$$

$$\{\phi_{0r}\}^T (\lambda_{0r}[\mathbf{M}'] + \lambda_r'[\mathbf{M}_0] - [\mathbf{K}']) \{\phi_{0r}\} = 0 \quad (3-8)$$

$$\begin{aligned} \{\phi_{0r}\}^T [M_0] \{\phi_{0r}\} &= 1 \\ \{\phi_{0r}\}^T [K_0] \{\phi_{0r}\} &= \lambda_{0r} \end{aligned} \tag{3-9}$$

(3-8) (3-9)

$$\lambda_r' = \{\phi_{0r}\}^T ([K'] - \lambda_{0r}[M']) \{\phi_{0r}\} \tag{3-10}$$

가 $[K']$, $[M']$ r

$$\{\phi_{0r}\}$$

$$\cdot \quad (3-7) \quad 0$$

$$\{\phi_{0r}\}$$

가 .

$$\{\phi_r'\} = [\phi_0] \{\xi_r\} \quad (3-11)$$

$$(3-7) \quad , \quad [\phi_0]^T \quad ,$$

$$\xi_s = \frac{\{\phi_{0s}\}^T (\lambda_{0r} [M'] + \lambda_r' [M_0] - [K']) \{\phi_{0r}\}}{\lambda_{0s} - \lambda_{0r}} ; s \neq r \quad (3-12)$$

$$, \quad s = r \quad (3-9) \quad \gamma \quad (3-11)$$

$$2\{\phi_{0s}\}^T [M_0] [\phi_0] \{\xi\} + \{\phi_{0s}\}^T [M'] \{\phi_{0r}\} = 0 \quad (3-13)$$

$$\xi_{s=r} = \frac{-\{\phi_{0r}\}^T [M'] \{\phi_{0r}\}}{2} \quad (3-14)$$

(3-12) (3-14) (3-11)

[K'], [M'], λ_{0r} , [ϕ_0]

, (3-11)

[ϕ]가

가

, (3-11)

, (3-12)

λ_{0s} 가 λ_{0r}

ξ_s 가

s

$\lambda_{0s} \gg \lambda_{0r}$

(3-15)

$\xi \approx 0$

가

, (3-3) 1

(3-3)

가

3.2

$\{\Delta\gamma\}$, $[A]$, $\{\Delta\omega\}$,

$$[A] \{\Delta\gamma\} = \{\Delta\omega\} \quad (3-16)$$

1 , $[A]$ 가
가
S

$$S = | [A] \{\Delta\gamma\} - \{\Delta\omega\} | \quad (3-17)$$

가
가
가 S
가

$$S = \{\Delta\gamma\}^T \{\Delta\gamma\} \quad (3-18)$$

$[A]$ 가 가

$$\{\Delta\gamma\} = [A]^T ([A][A]^T)^{-1} \{\Delta\omega\} \quad (3-19)$$

가

$$(3-19) \quad ([A][A]^T)^{-1} [A][A]^T \quad [2]$$

가 가 .

$$[A]^{-1} = ([A]^T [A])^{-1} [A]^T \quad (3-20)$$

()

$$[A]^T [A] = [U]^T [\] [U] \quad (3-21)$$

, [U] , [] . [U] []
A

$$\lambda_1 \ \lambda_2 \ \lambda_3 \ \cdots \ \lambda_n \quad (3-22)$$

, (3-22)

$$v_1 \ v_2 \ v_3 \ \cdots \ v_n \quad (3-23)$$

$$[\] = \begin{bmatrix} \lambda_1 & & & 0 \\ & \lambda_2 & & \\ & & \ddots & \\ 0 & & & \lambda_n \end{bmatrix} \quad (3-24)$$

$$[U]^T = [v_1 \ \vdots \ v_2 \ \vdots \ \cdots \ \vdots \ v_n] \quad (3-25)$$

$$([\mathbf{U}]^T [\mathbf{A}] [\mathbf{U}])^{-1} = [\mathbf{U}] [\mathbf{\Lambda}]^{-1} [\mathbf{U}]^T \quad (3-26)$$

$[\mathbf{U}]$ 가 , $[\mathbf{\Lambda}]$ 가 . $[\mathbf{\Lambda}]^{-1}$

$$[\mathbf{\Lambda}]^{-1} = \begin{bmatrix} \lambda_1^{-1} & & & 0 \\ & \lambda_2^{-1} & & \\ & & \ddots & \\ 0 & & & \lambda_n^{-1} \end{bmatrix} \quad (3-27)$$

$$\lambda_i^{-1} = \begin{cases} \lambda_i^{-1} & (\lambda_i \neq 0) \\ 0 & (\lambda_i = 0) \end{cases} \quad (3-28)$$

, (3-20)

$[\mathbf{A}]^T [\mathbf{A}]$ 가

$\{\Delta\omega\}$ 가 0

(3-16)

0

$\{\Delta\omega\}$ 가 0

(non-trivial

solution)

4.

4.1

()
84mm
Fig. 4.1
1 가 가 2 가 가
, , 4
Fig.
4.2 4.3 21

ANSYS

. ANSYS

Fig. 4.1 f_1 가 , r_2 r_3

ANSYS

Table 4.1 . Table 4.2

ANSYS

가 , , 가 가

ANSYS

가

Fig. 4.4

4.5 r_2 (frequency response function ; FRF) , Fig. 4.6

r_3

ANSYS

. ANSYS

가

.

Table 4.1 ANSYS Capability at a Glance

	<ul style="list-style-type: none"> · ·
	<ul style="list-style-type: none"> · Modal Analysis <ul style="list-style-type: none"> - , · Harmonic Analysis <ul style="list-style-type: none"> - , 가 · Spectrum Analysis <ul style="list-style-type: none"> - , 가 , · Random Vibration Analysis <ul style="list-style-type: none"> - · Dynamic Analysis <ul style="list-style-type: none"> - - ,
	<ul style="list-style-type: none"> · , , , , · , 가 · , , · 1
	<ul style="list-style-type: none"> · 가 · · 가 · Snap-through Arc-length
	<ul style="list-style-type: none"> · 2 /3 , · ,

Table 4.2 Specification of a converter

MODEL	SY- 2000PCM	
GEAR RATIO	AHEAD 1	3.07 : 1
	AHEAD 2	2.54 : 1
	ASTERN	3.07 : 1
OIL CAPACITY	APPROX.	450L
OIL PRESSURE	CLUTCH OPERATION OIL	20 25 kgf/cm^2
	LUBRICATING OIL	2 4 kgf/cm^2
OIL FILTER	SUCTION SIDE	32 MESH
	DELIVERY SIDE	150 MSEH
OIL COOLER	COOLING SURFACE AREA	2.8 m^2
	COOLING WATER MAX. FLOW	180 L/ min
SPARE PUMP CAPACITY	DELIVERY	117 L/ min
	PRESSURE	25 kgf/cm^2

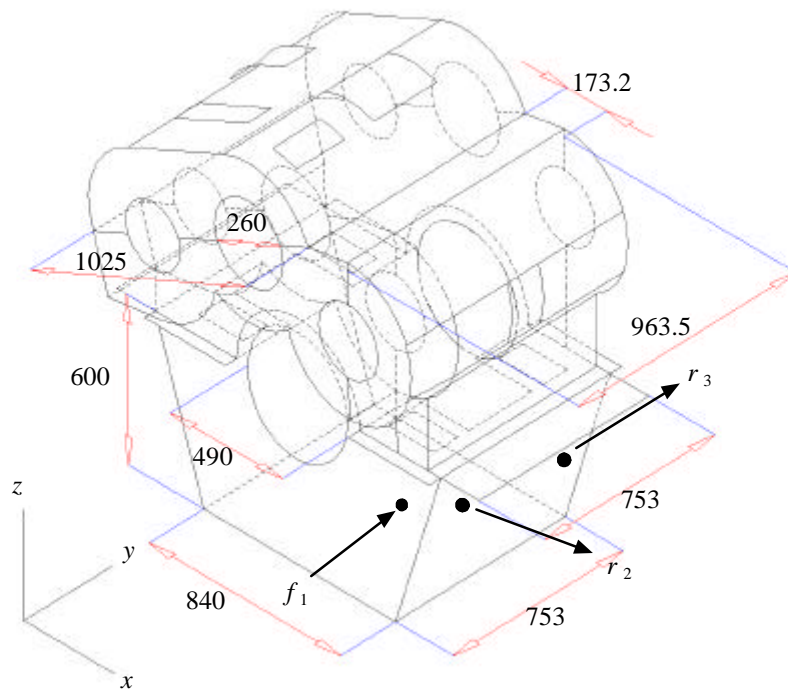


Fig. 4.1 The converter Model

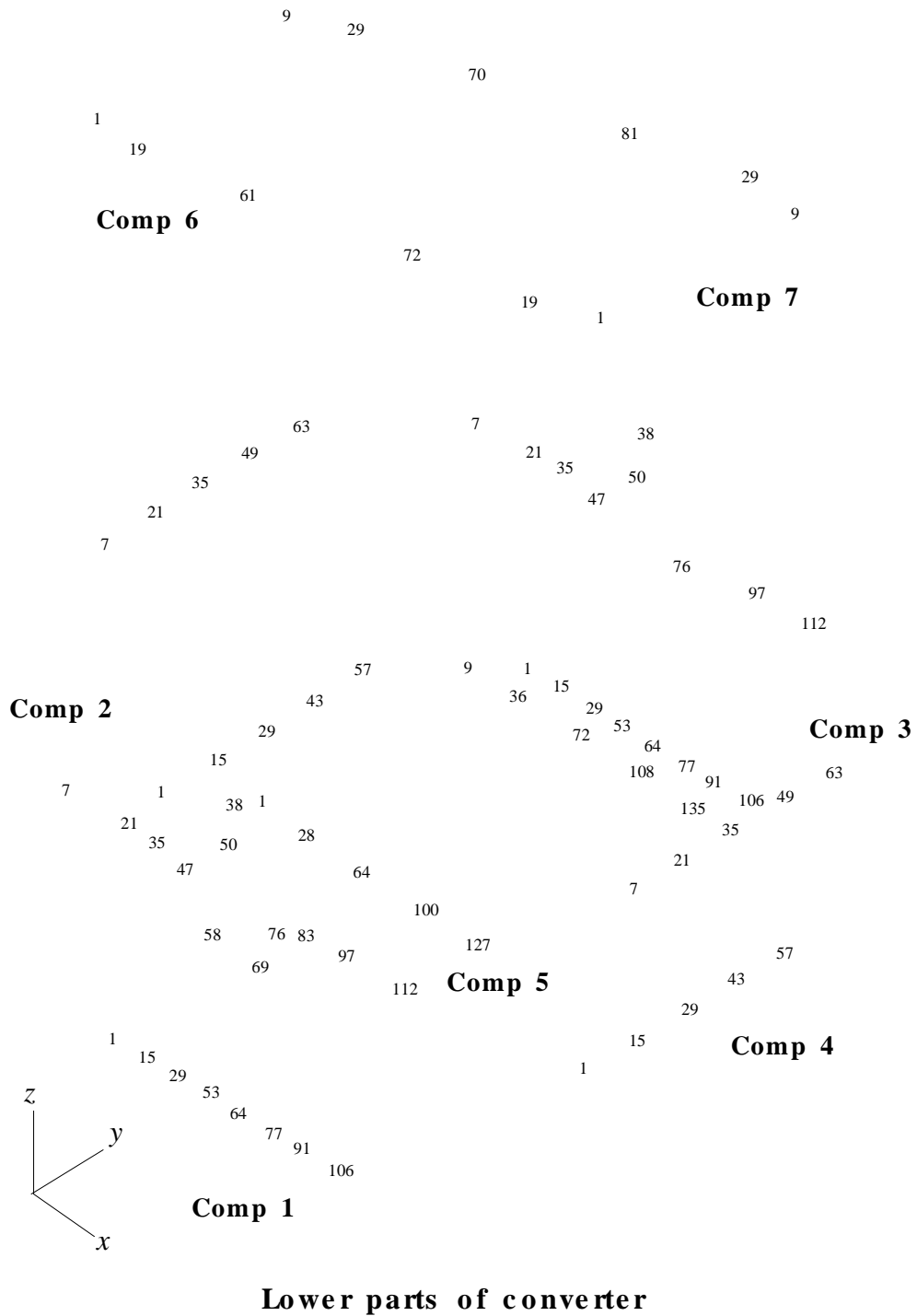


Fig. 4.2 FEM Model of the converter Model with 21 Sub-Structures (1)

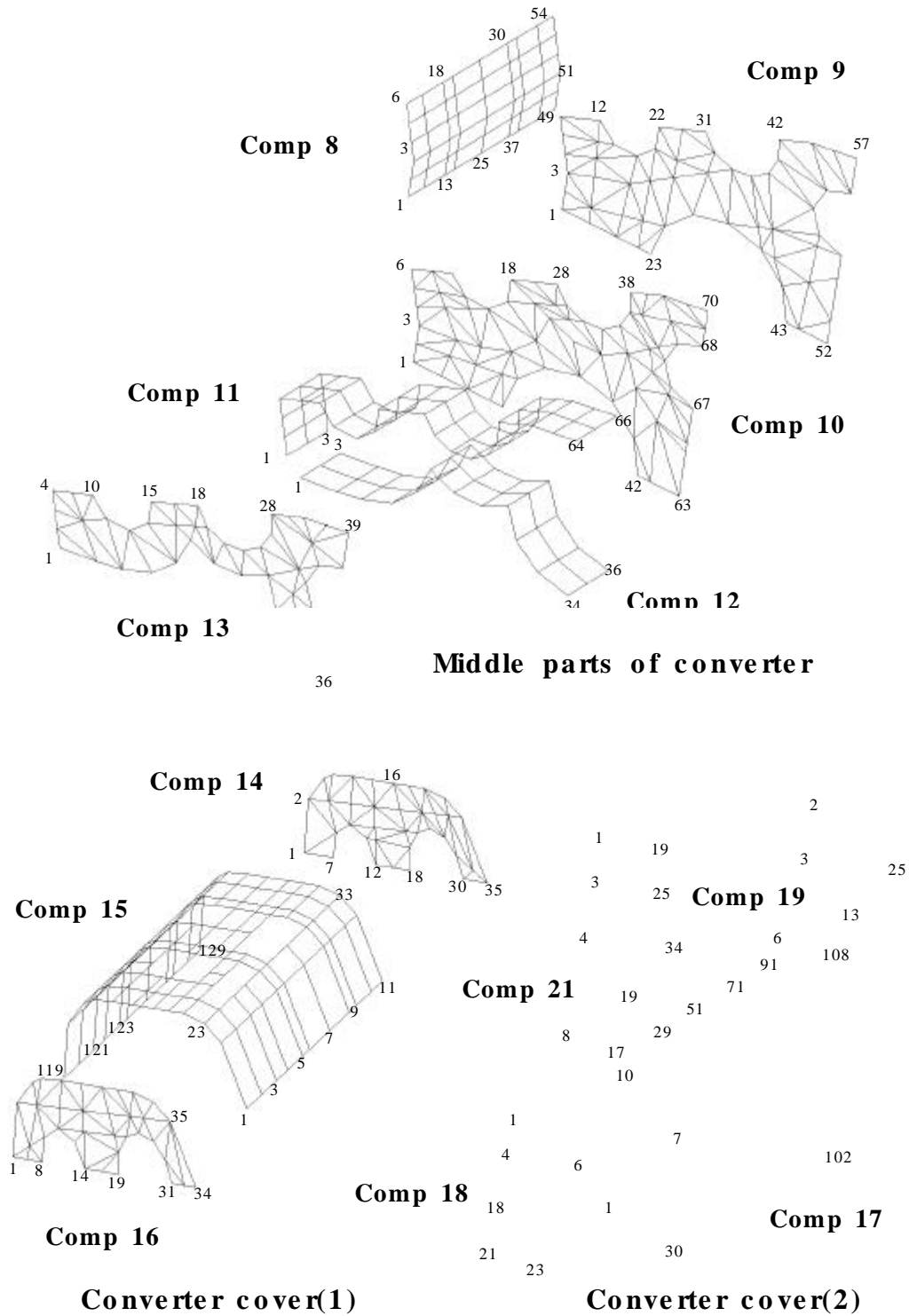
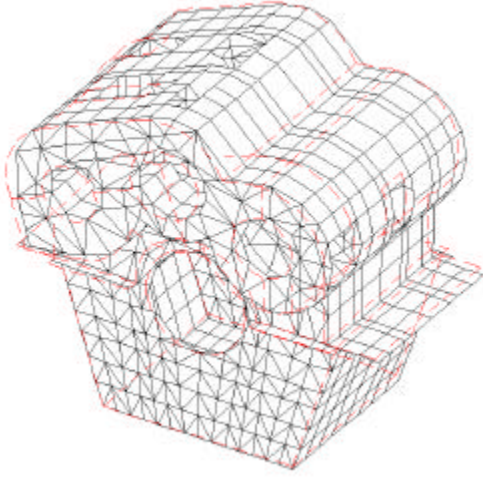
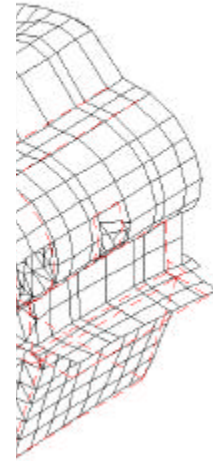


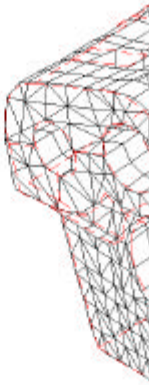
Fig. 4.3 FEM Model of the Converter Model with 21 Sub-Structures (2)



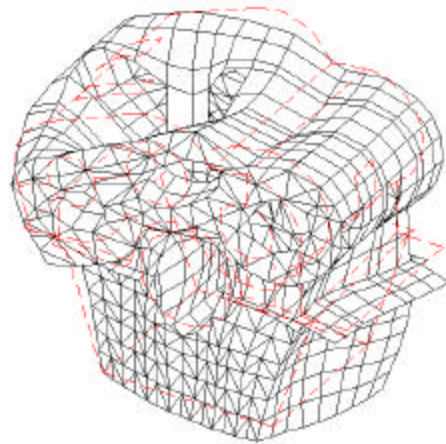
582.64 Hz



791.63 Hz



926.99 Hz



1035.52 Hz

Fig. 4.4 Natural modes of converter model

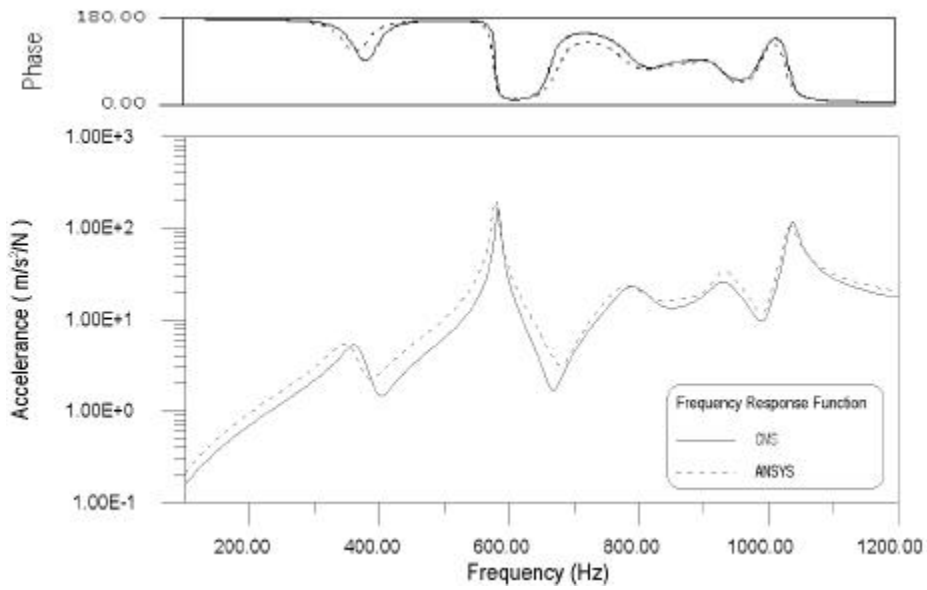


Fig. 4.5 Comparison with the result FRF of ANSYS and CMS (G21)

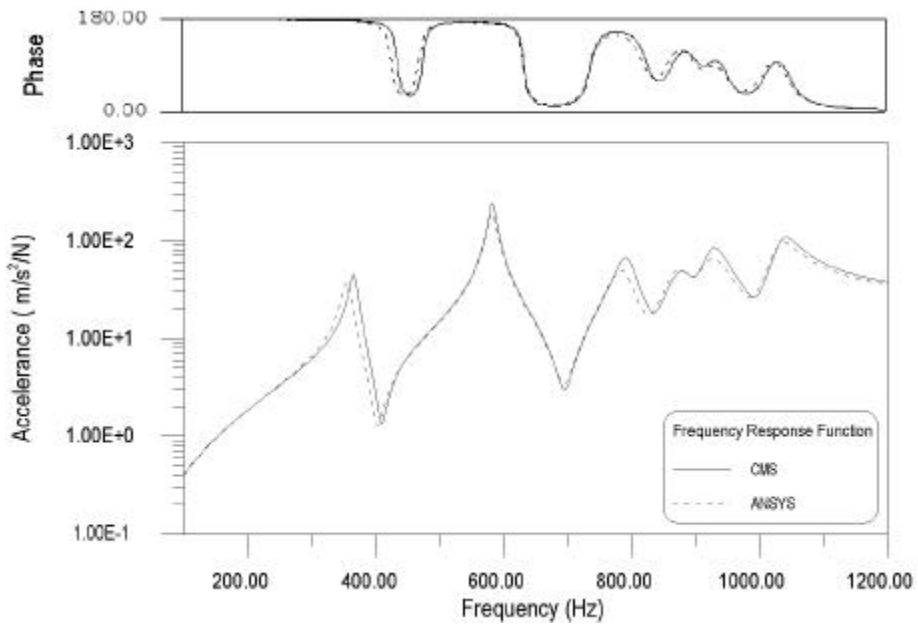


Fig. 4.6 Comparison with the result FRF of ANSYS and CMS (G31)

4.2

(2-6)	$\{\Delta\omega\}$ 가 {0}	$\{\Delta\gamma\}$
	$\{\Delta\gamma\}$ 가 {0}	
가		
가	가	가
	가	가
	가	가
	4	1, 2, 4
(84mm)	가	가
	42mm	가
	60mm, 70mm	

Table 4.3
84mm

Table 4.3 The natural frequencies before modification for various initial thickness (Hz)

order thickness	1	2	3	4	5	6
60mm	345.15	562.25	763.71	829.97	888.83	959.38
70mm	353.13	571.70	774.11	854.64	917.80	1023.96
84mm	366.16	582.64	791.63	877.07	926.99	1035.52

4.3

4.3.1

Table 4.4 60mm, 70mm

1, 2, 4

가

14 35

가

1

Table 4.5

60mm, 98.27 kgf 208.91 kgf

70mm 61.87 kgf 120.51 kgf

가

가

Fig. 4.7

60mm

, Fig. 4.8

70mm

Fig. 4.9

Fig. 4.11

1

20

가

3

20

○

Fig. 4.9

1

Fig. 4.10

2

가

Fig. 4.11

4

Fig. 4.12

Fig. 4.13

60mm, 70mm

1

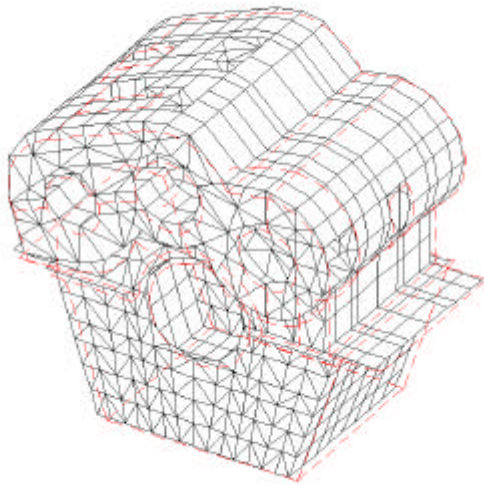
Fig. 4.14	Fig. 4.15	1	2		,
			60mm, 70mm	2	
		1	2		,
Fig. 4.16	Fig. 4.17		60mm, 70mm	4	
		1	2		.

Table 4.4 Coincidence of natural frequencies for initial thickness and numbers of natural frequency used for modification (Hz)

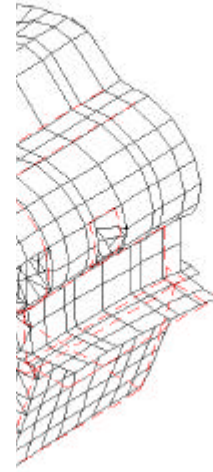
oder	84mm	initial thickness 60mm			initial thickness 70mm		
		1	2	4	1	2	4
1	366.16	365.91	366.04	365.47	366.13	365.77	365.75
2	582.64	569.31	581.17	579.83	575.96	580.83	578.43
3	791.63	765.74	791.15	790.14	775.78	790.64	790.75
4	877.07	846.59	866.28	876.13	862.09	870.94	874.90
5	926.99	908.20	925.96	926.52	921.73	926.87	924.60
6	1035.52	966.54	1017.10	1035.33	1017.17	1045.76	1035.53
iteration no.	-	14	26	35	15	17	20

Table 4.5 Reduction of weights after modification for various initial thickness (kgf)

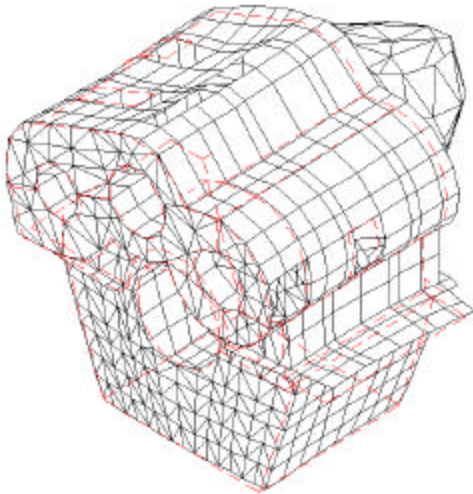
Weight	Origin (84mm)	Initial thickness 60mm			Initial thickness 70mm		
		1	2	4	1	2	4
Modified places	780.60	857.60	857.60	857.60	1050.50	1050.50	1050.50
After modification	-	571.69	675.78	682.33	660.09	713.44	718.73
Decreased (%)	-	208.91 (26.76)	104.82 (13.42)	98.27 (12.59)	120.51 (15.44)	67.16 (8.60)	61.87 (7.93)
Unmodified places	1940.96	1940.96	1940.96	1940.96	1940.96	1940.96	1940.96
Total reduction rate(%)	2721.56 (-)	2512.65 (7.68)	2616.74 (3.85)	2623.29 (3.61)	2601.05 (4.43)	2654.40 (2.47)	2659.69 (2.27)



579.83 Hz



790.14 Hz

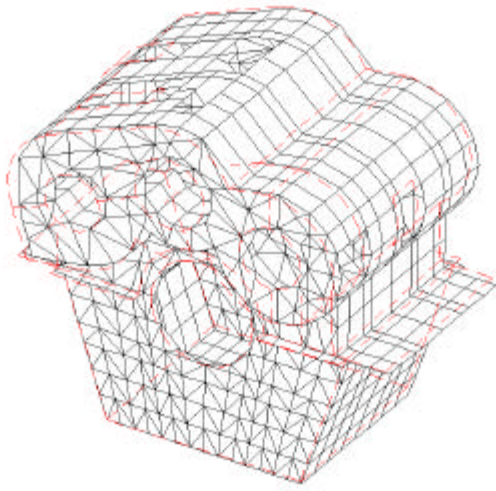


926.52 Hz

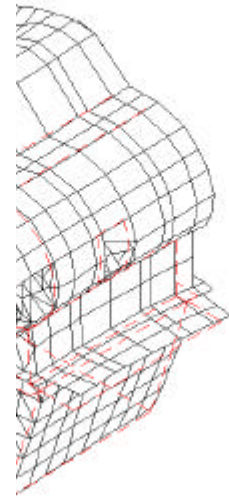


1035.33 Hz

Fig. 4.7 Natural modes after modification of at initial thickness 60mm



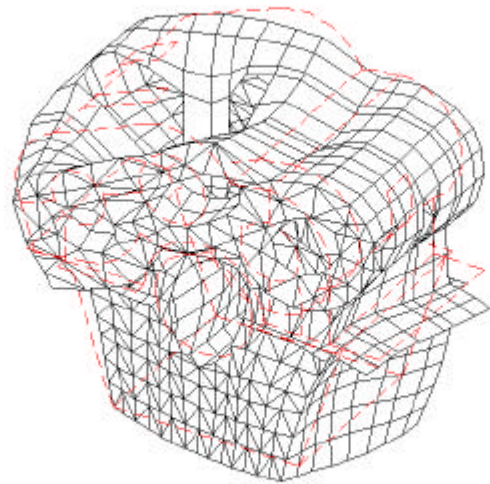
578.43 Hz



790.75 Hz



924.60 Hz



1035.53 Hz

Fig. 4.8 Natural modes after modification of at initial thickness 70mm

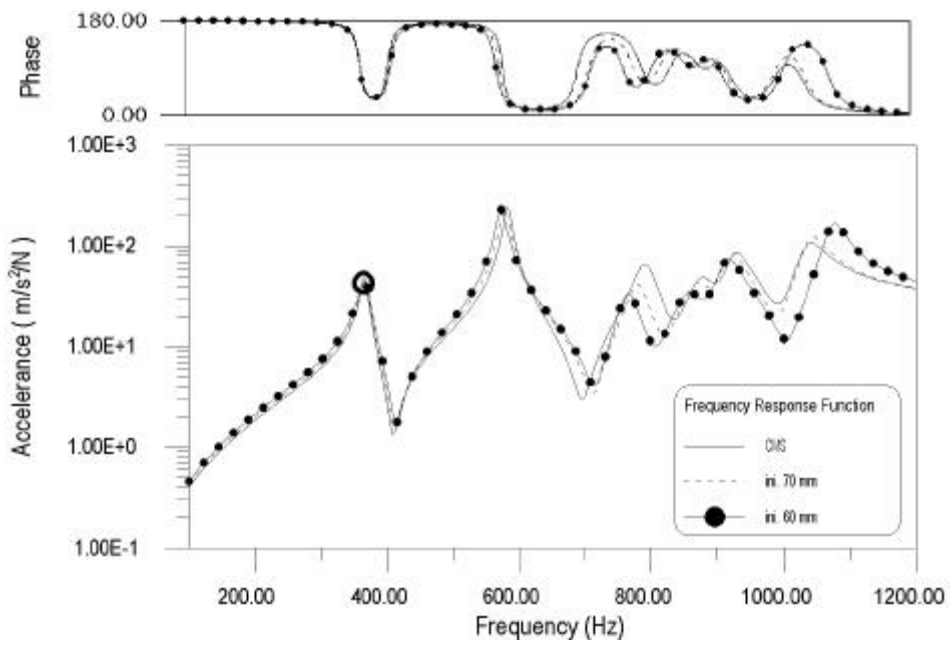


Fig. 4.9 FRF in case of 1 natural frequency fitted

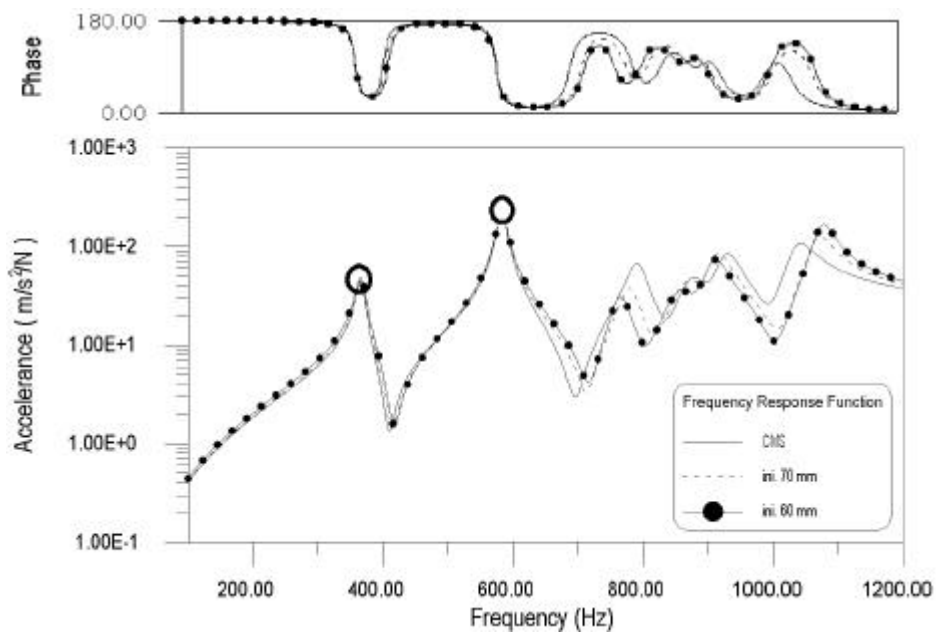


Fig. 4.10 FRF in case of 2 natural frequencies fitted

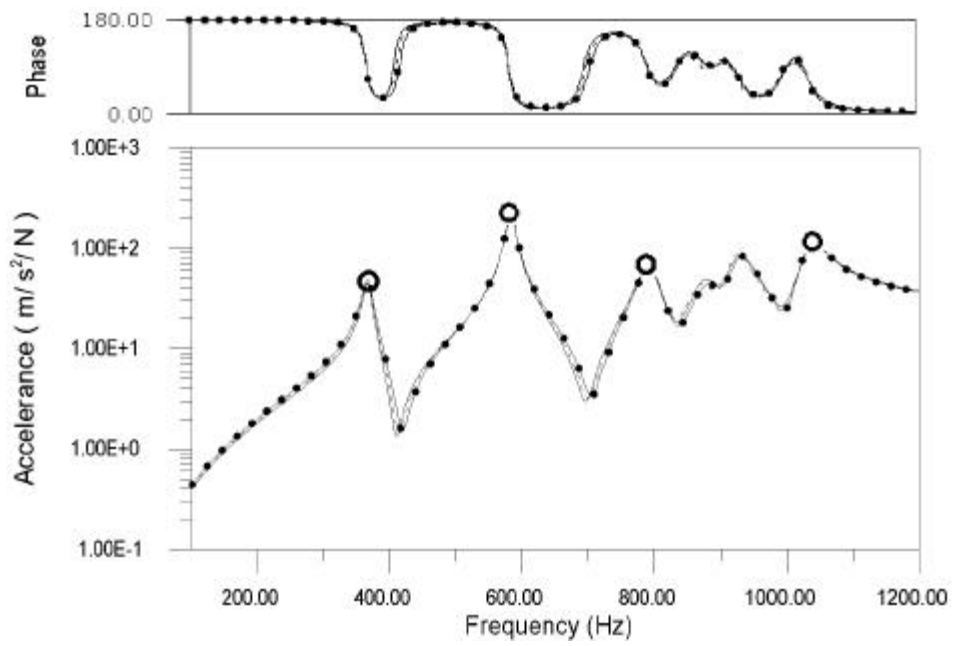


Fig. 4.11 FRF in case of 4 natural frequencies fitted

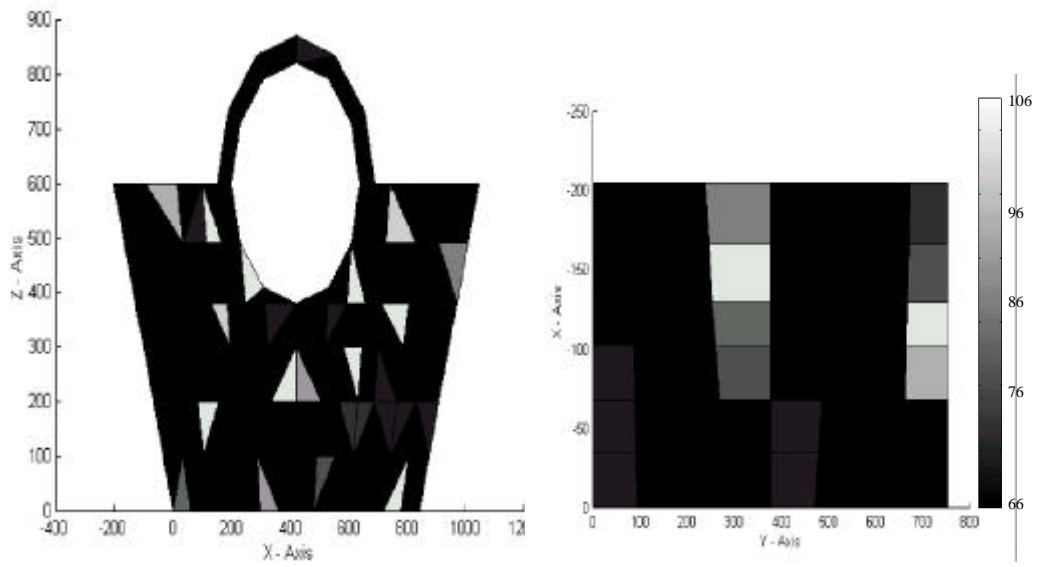


Fig. 4.12 The thickness distribution after modification of fitting 1 natural frequency at initial 60mm for the Converter

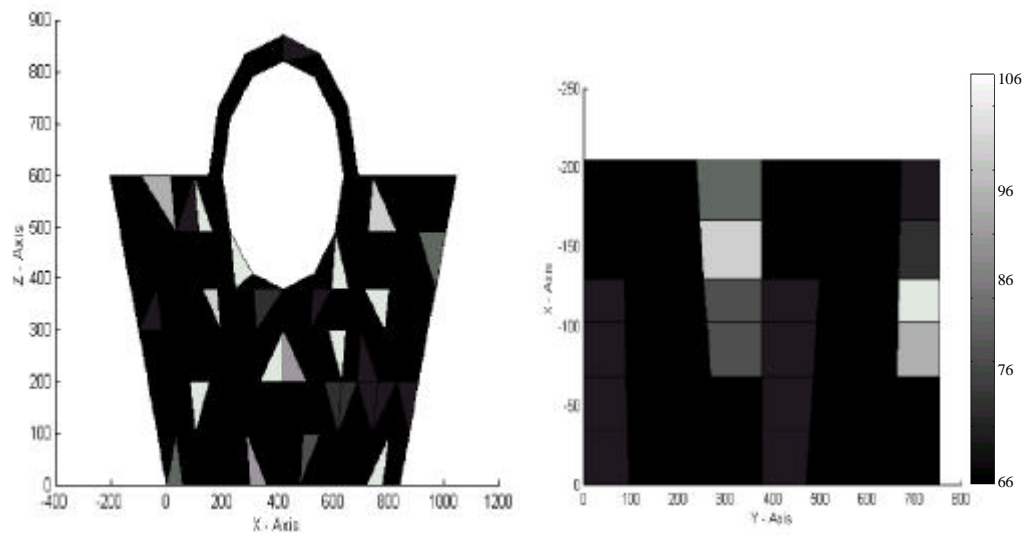


Fig. 4.13 The thickness distribution after modification of fitting 1 natural frequency at initial 70mm for the Converter

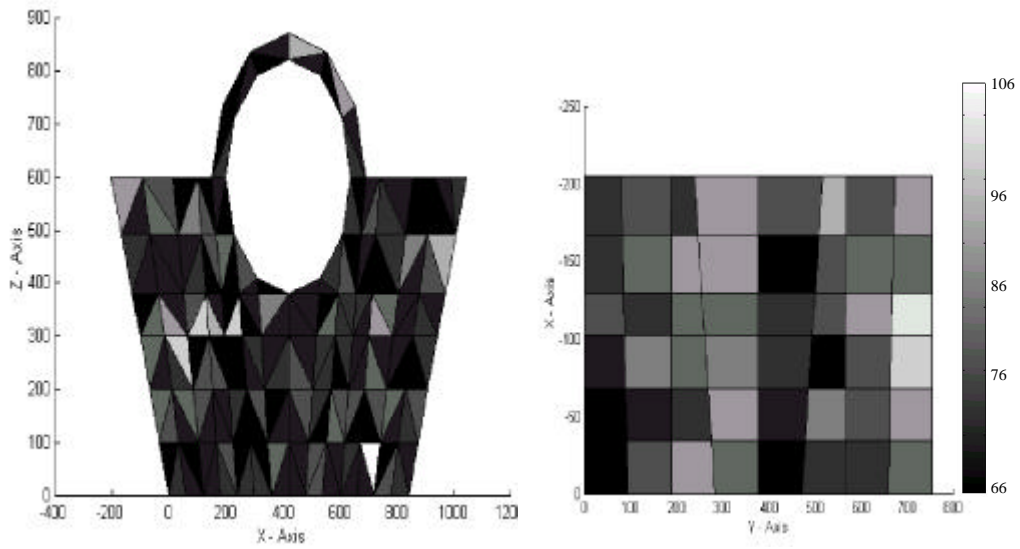


Fig. 4.14 The thickness distribution after modification of fitting 2 natural frequencies at initial 60mm for the Converter

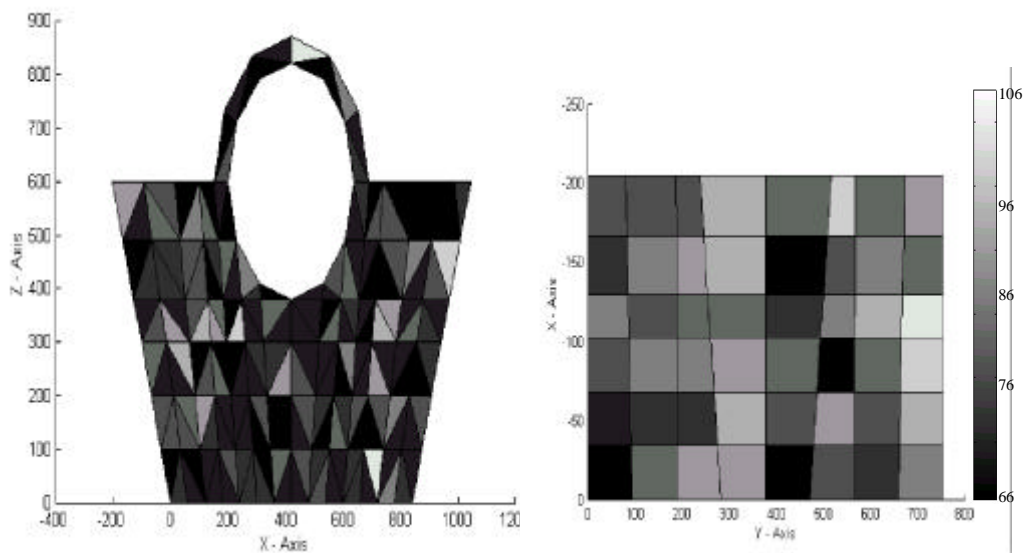


Fig. 4.15 The thickness distribution after modification of fitting 2 natural frequencies at initial 70mm for the Converter

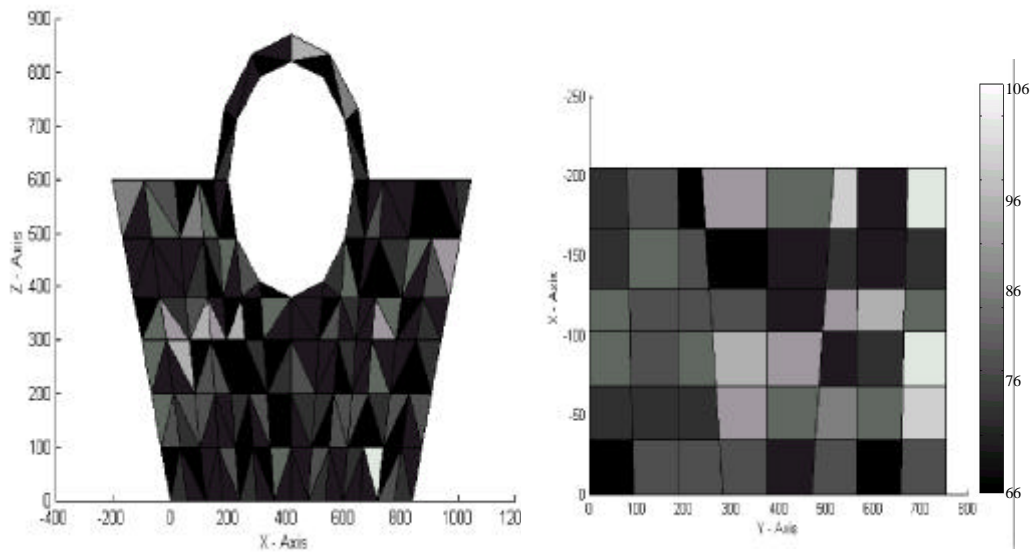


Fig. 4.16 The thickness distribution after modification of fitting 4 natural frequencies at initial 60mm for the Converter

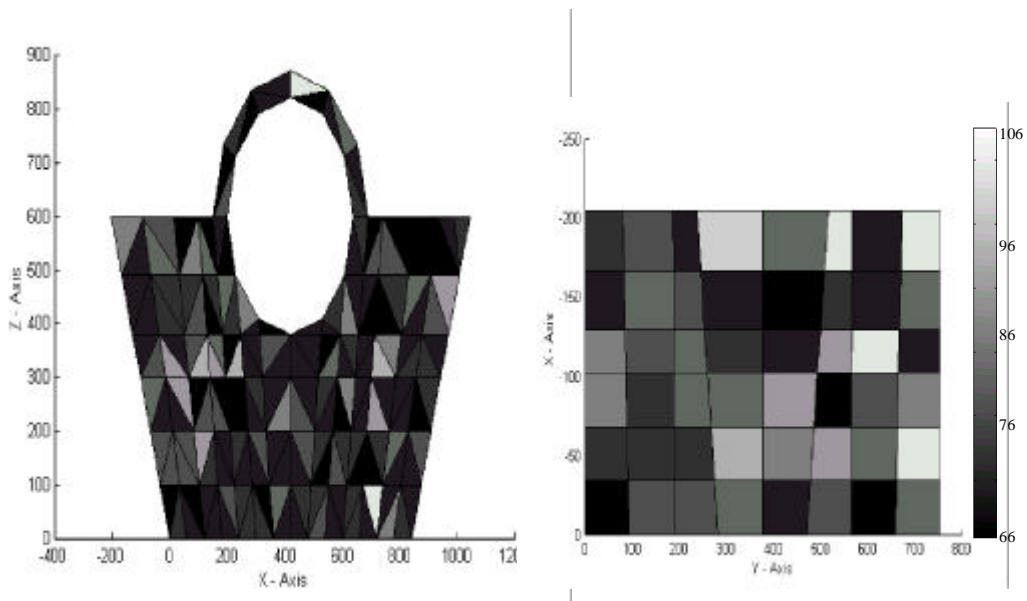


Fig. 4.17 The thickness distribution after modification of fitting 4 natural frequencies at initial 70mm for the Converter

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