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LIST OF APPENDICES

Appendix A: Two DOF model without damping


```
%Comparison of of forces in elements for two mounting cases (affecting k1)
%No Damping is assumed
%Pieter Vergeer

clear;
clc;

tel = 330;          %amount of frequencies in result
uit = 106
kies = 1

m1 = 22.255;        %Mass connected to top structure [kg]
m2 = 24.007;         %Mass connected to bottom structure [kg]
M = [m1 0;0 m2 ];

kmi = 20718;        %Individual stiffness of mounts [N/m]
Nm = 6;             %number of mounts
kci = 36529;      %Individual stiffness of compensators [N/m]
kp = 319997;       %Stiffness of plates [N/m]

k2 = kp;            %Stiffness between top and bottom structure (plates)
k3 = kci;           %Stiffness between bottom and frame
k1(1) = Nm*kmi+kci; %Elasticmounted case stiffness between top and frame
k1(2) = 1000*k2;    %Bolted case stiffness between top and frame

w = zeros(tel,1);

for j = 1:2
    K = [k1(j)+k2 -k2 ; -k2 k2+k3];

    [V,D] = eig(K,M);
    run = j
    omega1 = sqrt(D(1,1));   %First natural frequency of system
    f1 = omega1/(2*pi)
    omega2 = sqrt(D(2,2));   %Second natural frequency of system
    f2 = omega2/(2*pi)

    for i = 1:tel
        w(i) = i;

        F0(:,i) = [0 ; 0.002238244*w(i)^2];    %Amplitude of oscillating force

        A = (-M*w(i)^2 + K);
        X = linsolve (A,F0(:,i));

        F1(i,j) = X(1)* k1(j);          %Force transmitted through k1
        F2(i,j) = (X(2)-X(1)) * k2;     %Force transmitted through k2
        F3(i,j) = X(2) * k3;            %Force transmitted through k3

        X1(i,j) = X(1);
        X2(i,j) = X(2);
```

```
    end
end

%Results
X1RMS = abs(0.707*X1);
X2RMS = abs(0.707*X2);
F1RMS = abs(0.707*F1);
F2RMS = abs(0.707*F2);
F3RMS = abs(0.707*F3);

for i = 1:tel
    RAT1(i,1) = F1RMS(i,1)/F1RMS(i,2);
    RAT2(i,1) = F2RMS(i,1)/F2RMS(i,2);
    RAT3(i,1) = F3RMS(i,1)/F3RMS(i,2);
end

%plot
figure(1);
clf;
plot (w/(2*pi),abs(X1(:,1)),'-g');
axis ([0 50 0 0.005]);
hold on;
plot (w/(2*pi),abs(X1(:,2)),'-r');
title('Comparison of X1 between Elastic Mounted and Bolted Cases');
xlabel('Frequency of oscillating force [Hz]');
ylabel('Absolute displacement of top (abs(X1)) [m]');
grid on;
legend ('Elastic mounted','Bolted');

figure(2);
clf;
plot (w/(2*pi),abs(X2(:,1)),'-g');
axis ([0 50 0 0.005]);
hold on;
plot (w/(2*pi),abs(X2(:,2)),'-r');
title('Comparison of X2 between Elastic Mounted and Bolted Cases');
xlabel('Frequency of oscillating force [Hz]');
ylabel('Absolute displacement of bottom (abs(X2)) [m]');
grid on;
legend ('Elastic mounted','Bolted');

figure(3);
clf;
plot (w/(2*pi),abs(F1RMS(:,1)),'-g');
axis ([0 50 0 500]);
hold on;
plot (w/(2*pi),abs(F1RMS(:,2)),'-r');
title('Comparison of F1 between Elastic Mounted and Bolted Cases');
xlabel('Frequency of oscillating force [Hz]');
ylabel('Absolute force in element k1 (abs(F1RMS)) [N]');
legend ('Elastic mounted','Bolted');
```

```
grid on;

figure(4);
clf;
plot (w/(2*pi),abs(F2RMS(:,1)),'-g');
axis ([0 50 0 500]);
hold on;
plot (w/(2*pi),abs(F2RMS(:,2)),'-r');
title('Comparison of F2 between Elastic Mounted and Bolted Cases');
xlabel('Frequency of oscillating force [Hz]');
ylabel('Absolute force in element k2 (abs(F2RMS)) [N]');
grid on;
legend ('Elastic mounted','Bolted');

figure(5);
clf;
plot (w/(2*pi),abs(F3RMS(:,1)),'-g');
axis ([0 50 0 500]);
hold on;
plot (w/(2*pi),abs(F3RMS(:,2)),'-r');
title('Comparison of F3 between Elastic Mounted and Bolted Cases');
xlabel('Frequency of oscillating force [Hz]');
ylabel('Absolute force in element k3 (abs(F3RMS)) [N]');
grid on;
legend ('Elastic mounted','Bolted');

figure (7);
clf;
plot (w/(2*pi),F0(2,:),'-b');
title('Amplitude of Oscillating Force');
xlabel('Frequency of motor [Hz]');
ylabel('Amplitude of oscillatig force [N]')

figure (6);
clf;
axis ([0 50 0 200]);
hold on;
title('Force Ratio between Elastic Mounted and Bolted Cases');
xlabel('Frequency of oscillating force [Hz]');
ylabel...
('Force in elastically mounted case / Force in Bolted case [%]');
plot (w/(2*pi),abs(RAT1)*100,'-b');
plot (w/(2*pi),abs(RAT2)*100,'-g');
plot (w/(2*pi),abs(RAT3)*100,'-r');
legend ('Force ratio of F1','Force ratio of F2','Force ratio of F3');
plot (w/(2*pi),100,'-k');
plot (w/(2*pi),50),'-k';
```

```
for i = 1 :200
plot (75/(2*pi),i,'-k');
plot (106/(2*pi),i,'-k');
% plot (uit/(2*pi),i,'.b');
end

k1_uit = k1(kies)
k2
k3
m1
m2

F0_uit = F0(2,uit)
X1_uit = X1(uit,kies)
X2_uit = X2(uit,kies)
X1dotdot1_uit = -X1_uit*uit^2*M(1,1)
X2dotdot2_uit = -X2_uit*uit^2*M(2,2)
F1_uit = F1(uit,kies)
F2_uit = F2(uit,kies)
F3_uit = F3(uit,kies)
```

Appendix B: Two DOF model with damping


```
%Determine forces for 2 DOF system with damping
%Runga Kutta integration

clc;
clear;

load K.dat;           %stiffness matrix
load C.dat;           %damping matrix
load w.dat;           %Forcing frequency

dt = 2*pi/(10*w);     %Time steps
T = 1000*dt;           %Total time

%Sollution of Differential Equations
tspan = [0:dt:T];
y0 = [0; 0; 0; 0];
[t,y] = ode23('oplos',tspan,y0);        %integration

Fsum = [0,0,0];
Fsk = [0,0,0];
Fsc = [0,0,0];
Xsum = [0,0,0];

for i = round(0.5*(T/dt)):length(t);
        Fk(i,1) = ((K(1,1)+K(1,2))*y(i,1))^2;
        Fk(i,2) = (-K(1,2)*(y(i,3)-y(i,1)))^2;
        Fk(i,3) = ((K(2,2)+K(1,2))*y(i,3))^2;
        Fc(i,1) = ((C(1,1)+C(1,2))*y(i,2))^2;
        Fc(i,2) = (C(2,2)*(y(i,4)-y(i,2)))^2;
        Fc(i,3) = ((C(2,2)+C(1,2))*y(i,4))^2;
        X(i,1) = y(i,1)^2;
        X(i,2) = y(i,3)^2;
    for j = 1:2                        %iteration for displacements
        Xsum(j) = Xsum(j) + X(i,j)*dt;
    end
    for j = 1:3                        %iteration for forces
        Ftot(i,j) = Fk(i,j) + Fc(i,j);
        Fsum(j) = Fsum(j) + Ftot(i,j)*dt;
        Fsk(j) = Fsk(j) + Fk(i,j)*dt;
        Fsc(j) = Fsc(j) + Fc(i,j)*dt;
    end
end

FRMS(1) = sqrt(Fsum(1)/(0.5*T));
FRMS(2) = sqrt(Fsum(2)/(0.5*T));
FRMS(3) = sqrt(Fsum(3)/(0.5*T))

FkRMS(1) = sqrt(Fsk(1)/(0.5*T));
FkRMS(2) = sqrt(Fsk(2)/(0.5*T));
FkRMS(3) = sqrt(Fsk(3)/(0.5*T))
```

```
FcRMS(1) = sqrt(Fsc(1)/(0.5*T));
FcRMS(2) = sqrt(Fsc(2)/(0.5*T));
FcRMS(3) = sqrt(Fsc(3)/(0.5*T))

XRMS(1) = sqrt(Xsum(1)/(0.5*T));
XRMS(2) = sqrt(Xsum(2)/(0.5*T))

%plot
figure (1);
clf;
subplot (211);
plot (t,y(:,1));
xlabel ('t [s]');
ylabel ('x1 [m]');
title ('Startup Response of x1 and x2 at 75 rad/s in the Elastic Mounted Case');
%axis([49 50 -0.02 0.02]);
subplot (212);
plot (t,y(:,3));
xlabel ('t [s]');
ylabel ('x2 [m]');
%title ('Startup response of x2');
%axis([49 50 -0.015 0.015]);

figure (2);
clf;
subplot (311);
plot (t,Ftot(:,1));
title('Resultant force in elements (k1 & c1) used for calculation of RMS');
xlabel ('t [s]');
ylabel ('F1 [N]');
subplot (312);
plot (t,Ftot(:,2));
title('Resultant force in elements (k2 & c2) used for calculation of RMS');
xlabel ('t [s]');
ylabel ('F2 [N]');
subplot (313);
plot (t,Ftot(:,3));
title('Resultant force in elements (k3 & c3) used for calculation of RMS');
xlabel ('t [s]');
ylabel ('F3 [N]');
```

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```
%Integration with Runga Kutta for 3x3 matrices with damping
%M,K,C,F0 and w .dat files

function f = oplos(t,y)

f = zeros(4,1);

load M.dat;          %mass matrix
load C.dat;          %Damping matrix
load K.dat;          %Stiffness matrix
load F0.dat;         %Force matrix
load w.dat;        %Forcing frequency

F0 = F0*w^2       %Calculation of unbalanced force

f(1) = y(2);
f(2) = (F0(1)*sin(w(1)*t) + C(1,2)*y(4) - C(1,1)*y(2) + K(1,2)*y(3) - K(1,1)*y(1))/M↙
(1,1);

f(3) = y(4);
f(4) = (F0(2)*sin(w(1)*t) + C(2,1)*y(2) - C(2,2)*y(4) + K(2,1)*y(1) - K(2,2)*y(3))/M↙
(2,2);
```

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```
22.255  0
0   24.007
```

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```
480834  -319997
-319997 356526
```

10/18/11 7:16 PM C:\Users\user\Documents\Magister\Verhadeling\Modelle\...\C.dat 1 of 1

```
343.979 -43.699
-43.699 70.529
```

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```
0
0.002238244
```

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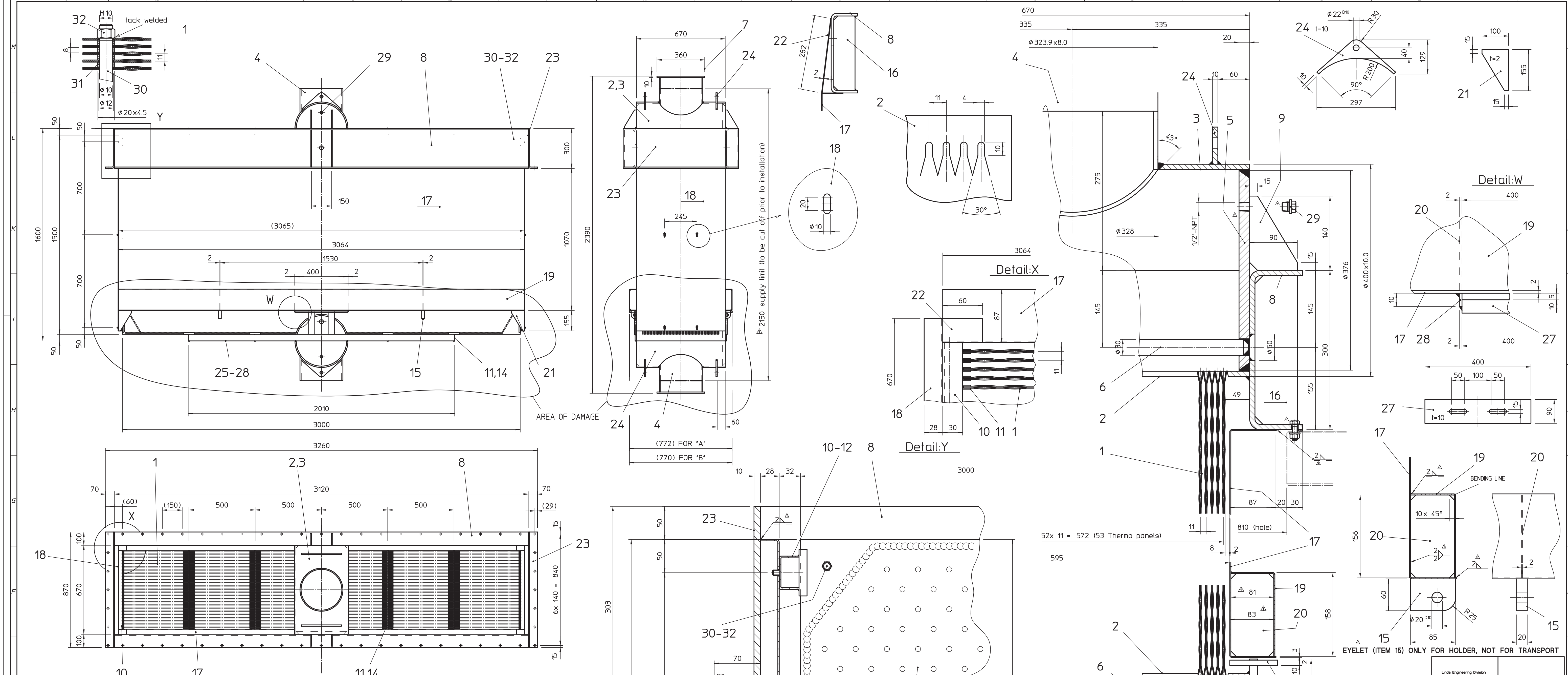
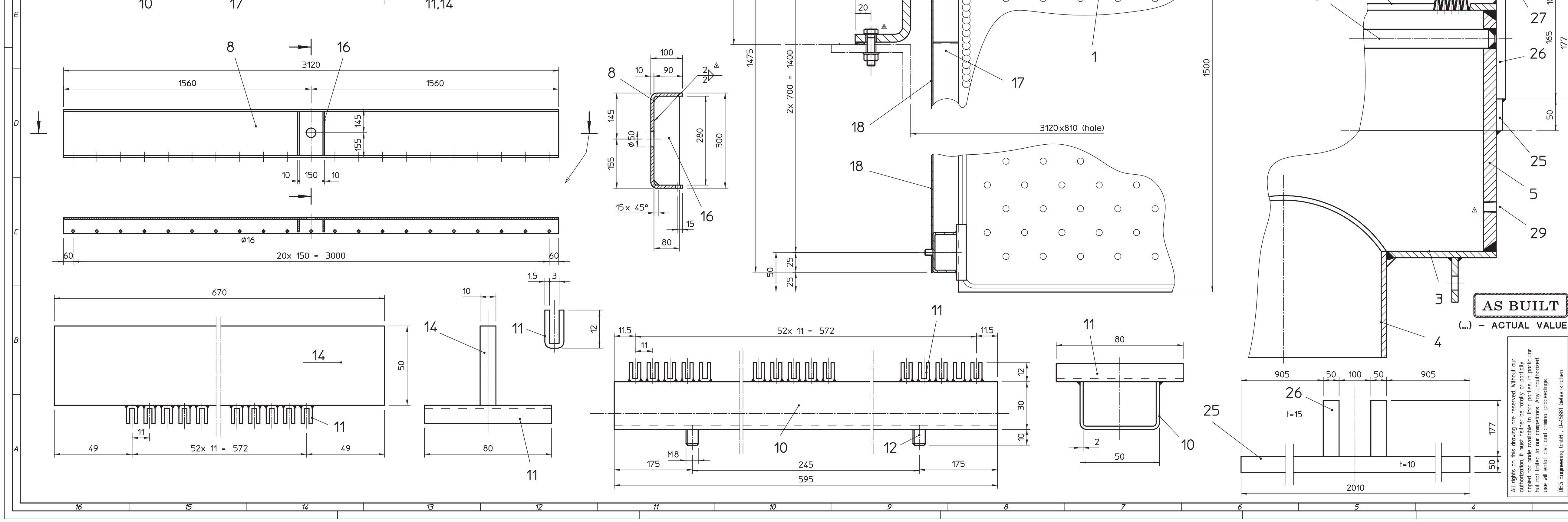
```
75
```

Appendix C: DEG engineering drawing: Panel bank 301EX-2491 A/B





Linde Engineering Division	
Linde Job No.: 2120 0184	1- Octene Train 2 Plant
Linde Job No.: Secunda 47	Sasol Contract No. 450 400 0039
Linde Doc. No. BZE 5019.004 ⚠2	Sasol Doc. No. 301.4018.004 ⚠2

▵ TESTING INSTRUCTIONS:

THE TESTING OF THE CONDENSER CASING TO BE CARRIED OUT ONLY WITH THE THERMO-PLATE BANK FILLED WITH DEMINERALIZED/CHLORIDE-FREE WATER AND CLOSED.

PLEASE PAY ATTENTION!!

FOR THE HYDROSTATIC PRESSURE TEST OF THE CONDENSER TOGETHER WITH THE COLUMN IN A HORIZONTAL POSITION THE BLEEDER SCREW ITEM ▵29 MUST BE CLOSED AND WELDED AFTER FILLING WITH WATER AND AIR RELEASE.

EXTERNAL SURFACE PROTECTION
STAINLESS, AUSTENETIC PARTS: PICKLED AND PASSIVATED
GLASS-FLOUR BLASTED

▵ BELONGS TO DRAWING 020-470-0 301VL-2401

Design acc. to: AD-Merkblätter; Druckgeräterichtlinie Modul G
Ausführung nach:

		Shell side (Mantelseite)	Thermo plate side (Thermo-Blech-Seite)		
Design pressure gauge: / Zulässiger Betriebsüberdruck:	bar	-0,85/4	-0,85/10	Inspection by: / Abnahme durch:	Manufacturer
Design temperature: / Zulässige Betriebstemperatur:	°C	0/190	0/190	Supervision of manuf. by: / Fertigungskontrolle durch:	MBS
Corrosion allowance / Abnutzungszuschlag	mm	0 ⚠2	0 ⚠2	Weight to be supplied: / Liefergewicht:	6376,0/piece kg
Other additional allowances / Sonstige Zuschläge	mm			Operation weight: / Betriebsgewicht:	kg
Joint effiency / Schweißfaktor		0,85	0,85	Weight at retest: / Gew. bei Wied.-prüfung:	kg
Nominal volume / Nennvolumen	l		920/piece	Bundle weight: / Bündelgewicht:	kg
Initial test pressure gauge: / Prüfüberdruck erstmalig:	bar		21,0 ⚠	Total heat exch. surf.: / Gesamtaustauschfläche:	454/piece m^2
with water/air vertical/horizontal / mit Wasser/Luft stehend/liegend				Mfr's Serial No: / Herstell-Nr.:	*
Operation pressure gauge: / Arbeitsüberdruck:	bar			Year of manufacture: / Herstelljahr:	2003
Operation temperature / Arbeitstemperatur	°C			Modul G Kategorie IV	
Retest pressure gauge: / Prüfüberdruck Wiederholungsprüfung:	bar				
with water/air at top in oper. position / mit Wasser/Luft am Kopf in Betriebslage					
Process fluid / Stoff					

Lockhofstrasse 3
D-45881 Gelsenkirchen
DEG ENGINEERING GMBH

No	Alterations	Date	Name
	as built	28.11.2003	Swirkowski
⚠2	redesigned	29.09.2003	Swirkowski
⚠1	redesigned	21.08.2003	Swirkowski

	Date	Name
DRW.	22.05.2003	Swirkowski
CTR.		
APP.		

(22/1/03/084)

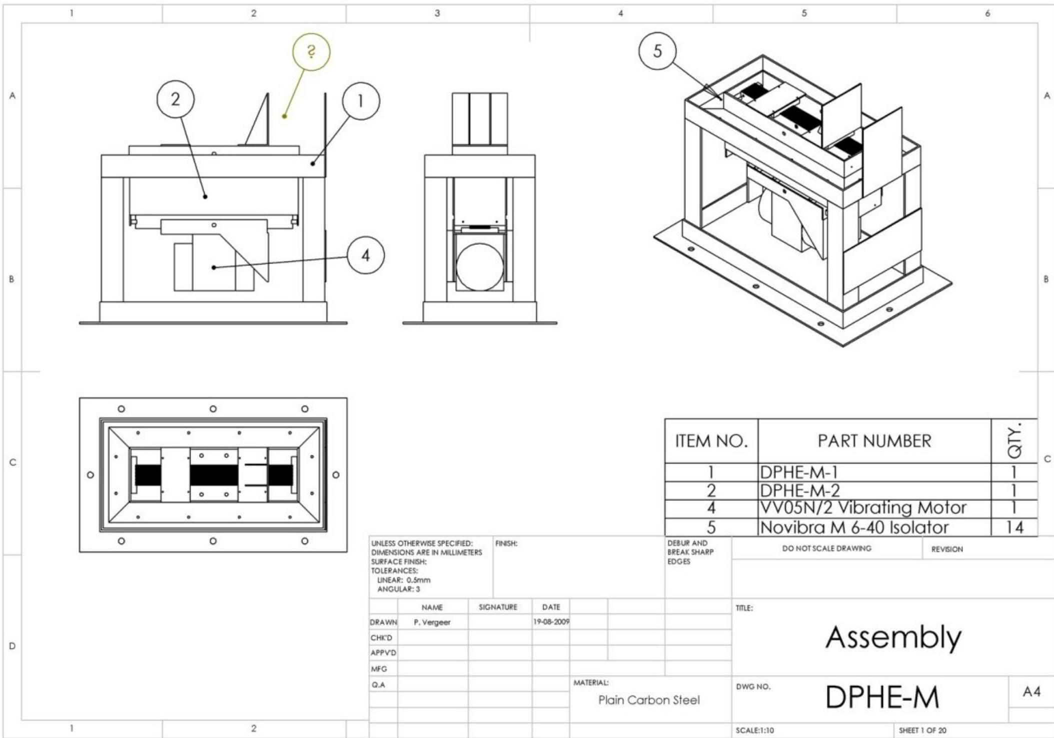
Scale 1:10 ;1:5 ;1:2,5 ;1:2 ;1:1 ;2:1
PARTSLIST NO
Weight
Material

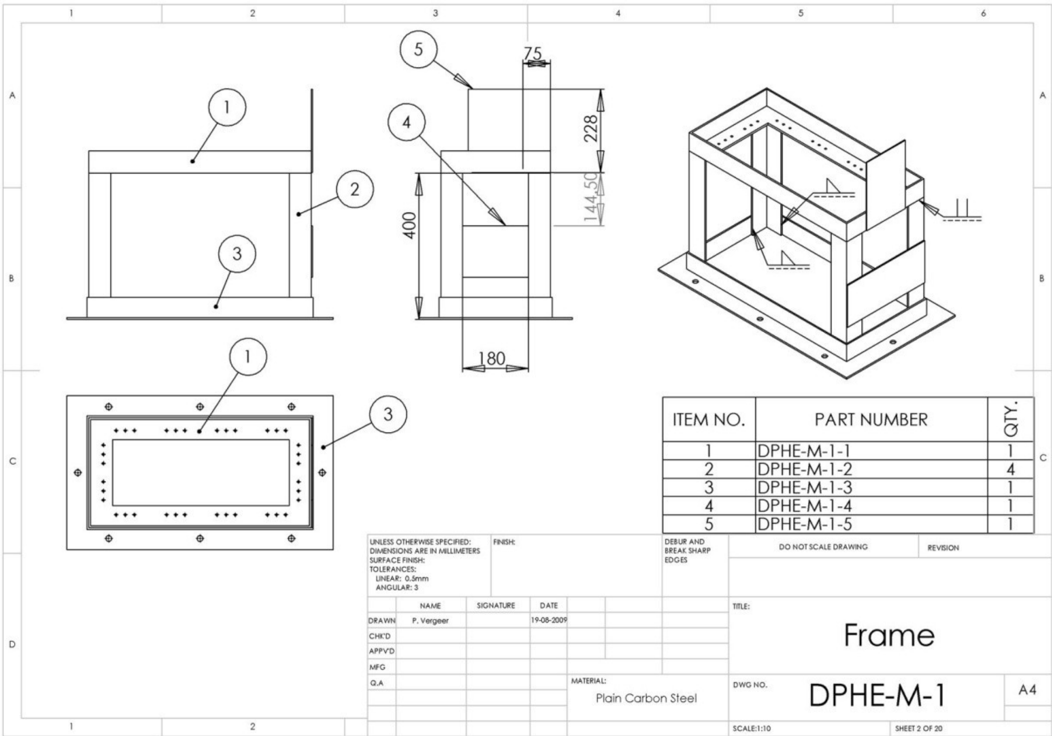
Assembly drawing
Panel bank 301EX-2401 A/B sheet 1/2

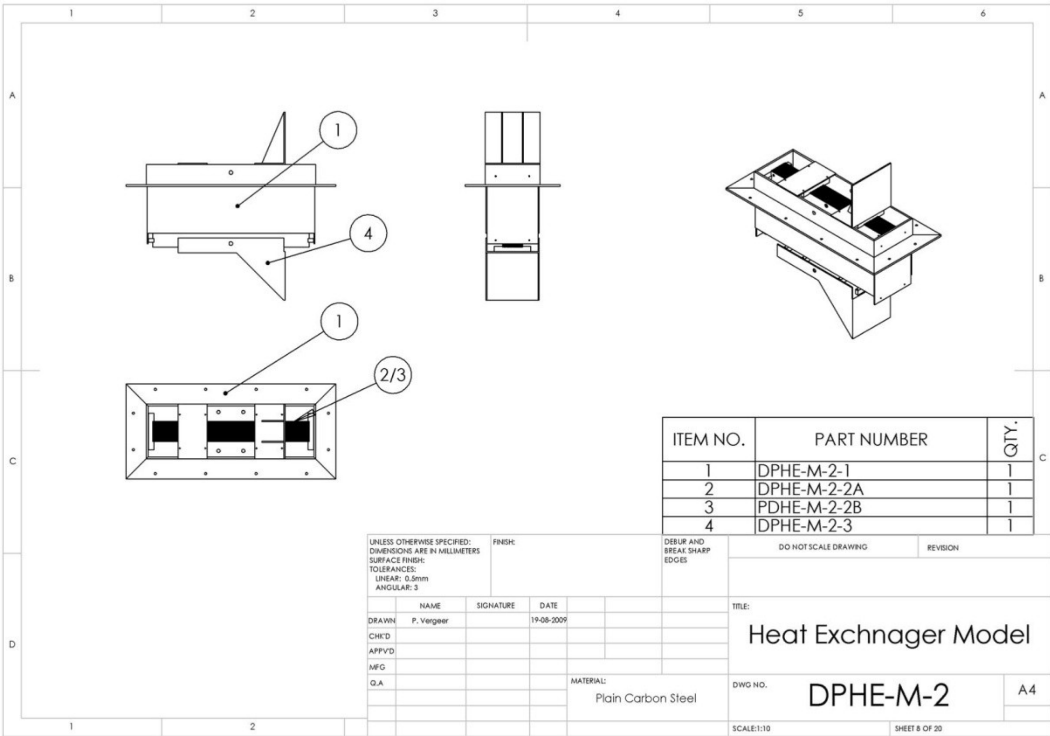
020-471-0 | 2

Repl. for: | Repl. by:

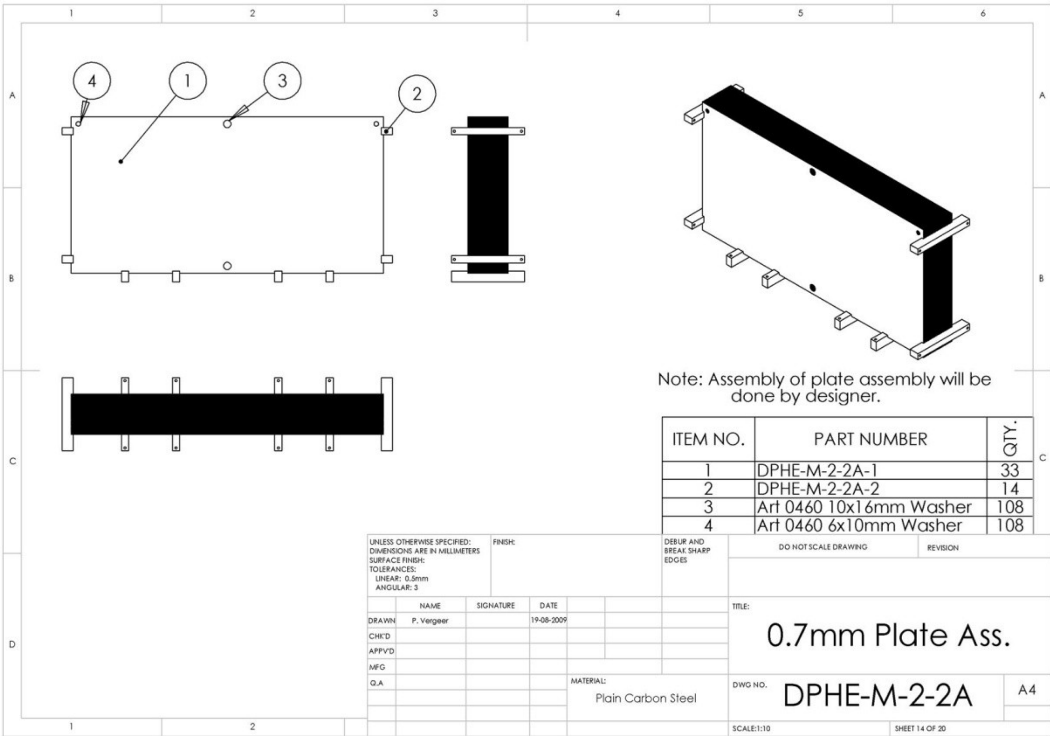
Appendix D: Design of vibration model



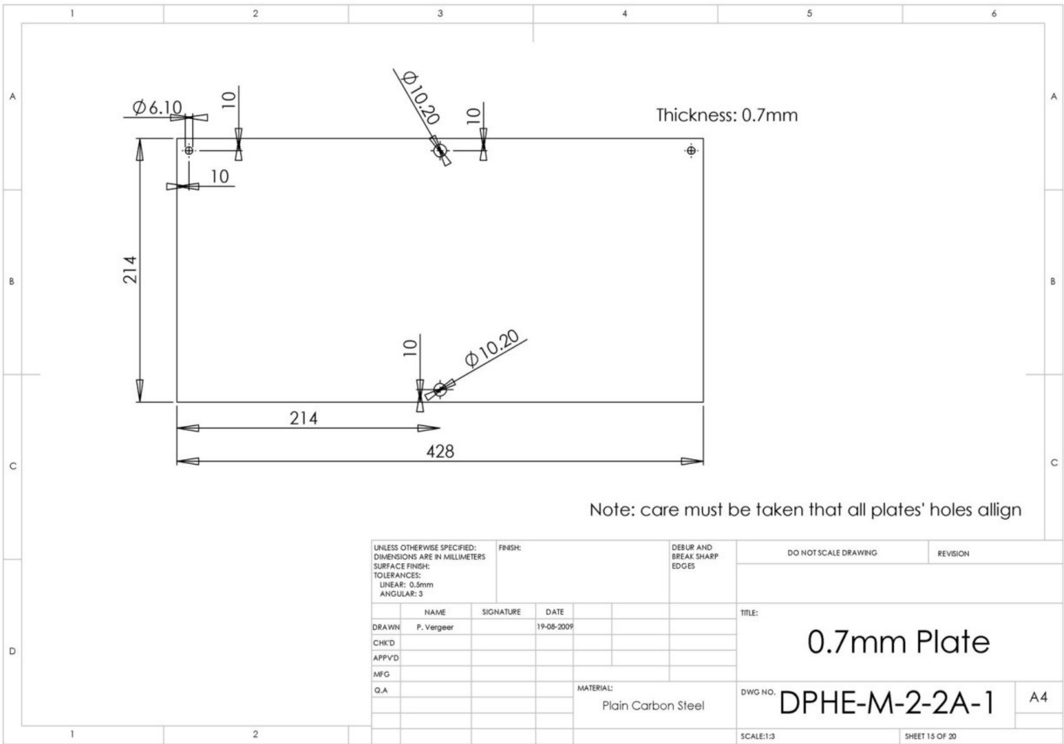


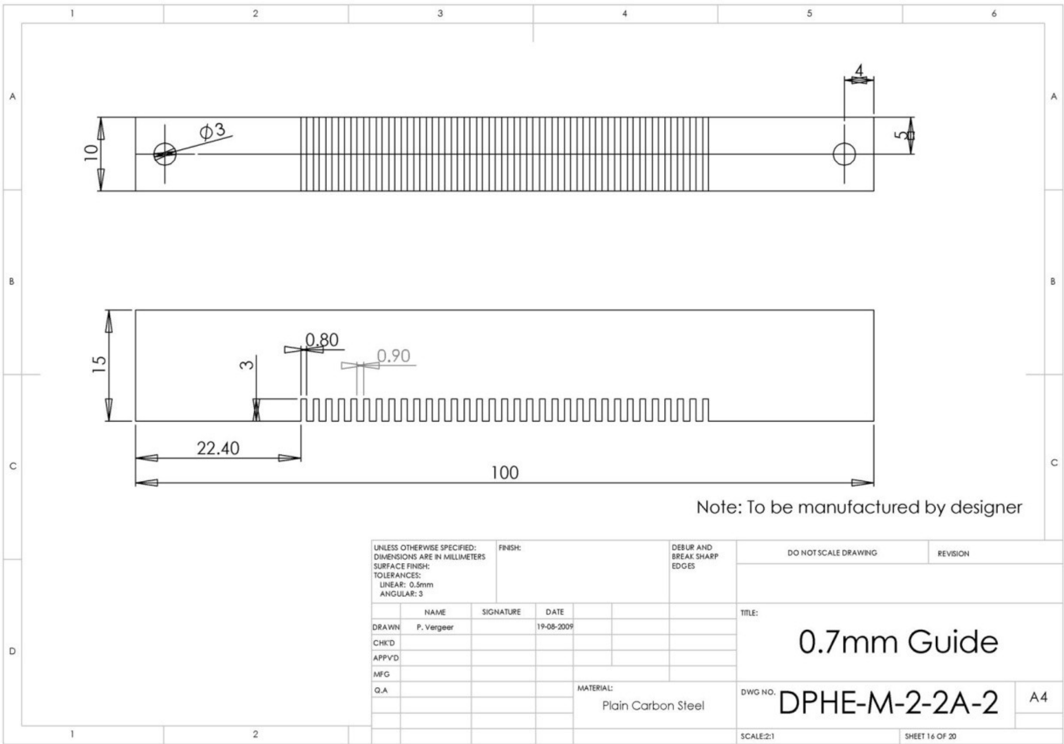


ITEM NO.	PART NUMBER	QTY.
1	DPHE-M-2-1	1
2	DPHE-M-2-2A	1
3	PDHE-M-2-2B	1
4	DPHE-M-2-3	1



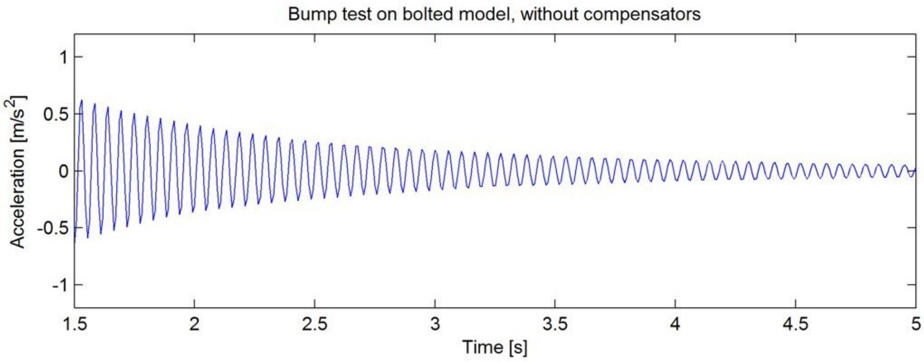
ITEM NO.	PART NUMBER	QTY.
1	DPHE-M-2-2A-1	33
2	DPHE-M-2-2A-2	14
3	Art 0460 10x16mm Washer	108
4	Art 0460 6x10mm Washer	108

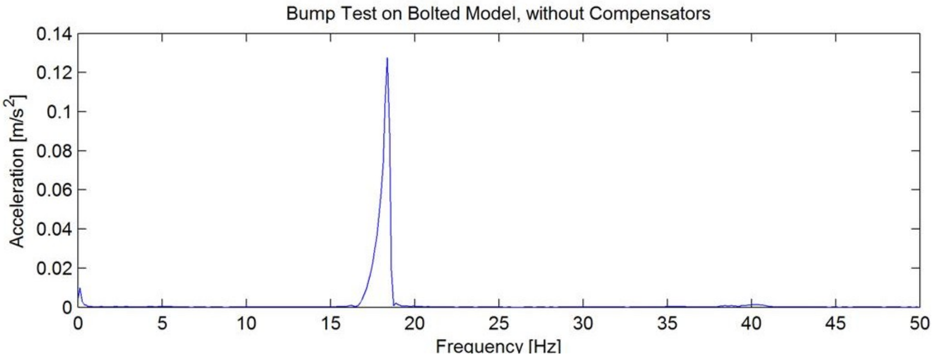

Ø6.10
10
10
Ø10.20
10
Thickness: 0.7mm
214
10
Ø10.20
214
428
Note: care must be taken that all plates' holes allign
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR: 0.5mm
ANGULAR: 3
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
P. Vergeer
19-08-2009
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
Plain Carbon Steel
TITLE:
0.7mm Plate
DWG NO.
DPHE-M-2-2A-1
A4
SCALE:1:3
SHEET 15 OF 20


4
Ø3
10
5
15
0.80
0.90
3
22.40
100
Note: To be manufactured by designer
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR: 0.5mm
ANGULAR: 3
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
P. Vergeer
19-08-2009
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
Plain Carbon Steel
TITLE:
0.7mm Guide
DWG NO.
DPHE-M-2-2A-2
A4
SCALE:2:1
SHEET 16 OF 20

Appendix E: Characterization of plate pack

Measured Natural Response of the System





Calculation of Damping Ratio

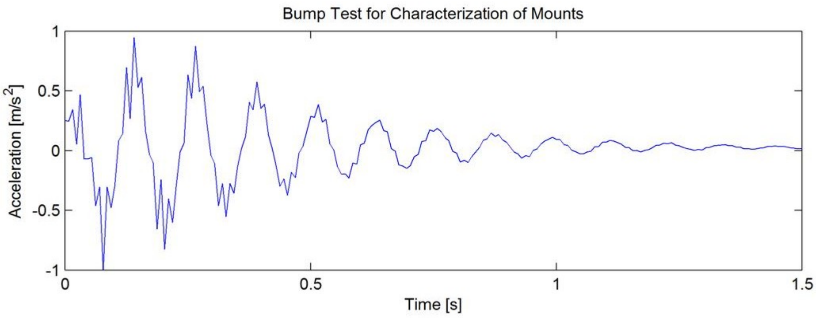
node	Point	Time [s]	Amplitude [m.s^{-2}]	Period [s]	log. decr.
1	197	1.53125	0.6241905		
2	204	1.585938	0.5909524	0.055	0.055
3	211	1.640625	0.5596696	0.055	0.054
4	218	1.695313	0.5303419	0.055	0.054
5	225	1.75	0.506391	0.055	0.046
6	232	1.804688	0.4834177	0.055	0.046
7	239	1.859375	0.4623995	0.055	0.044
8	246	1.914063	0.4399149	0.055	0.050
9	253	1.96875	0.4174304	0.055	0.052
10	260	2.023438	0.3954347	0.055	0.054
11	267	2.078125	0.3729501	0.055	0.059
12	274	2.132813	0.3558423	0.055	0.047
13	281	2.1875	0.3416673	0.055	0.041
14	288	2.242188	0.3255371	0.055	0.048
15	295	2.296875	0.3098956	0.055	0.049
16	302	2.351563	0.294743	0.055	0.050
17	309	2.40625	0.2771464	0.055	0.062
18	316	2.460938	0.2668817	0.055	0.038
19	323	2.515625	0.2531955	0.055	0.053
20	330	2.570313	0.242442	0.055	0.043
			average	0.055	0.050

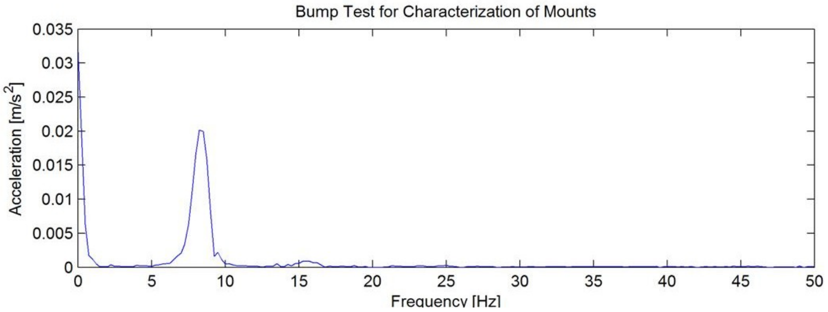
f_d	18.29	Hz
ω_d	114.89	rad/s
m_2	24.007	kg
N_p	1	plate pack
c	43.70	N. s/m
c_p	43.699	N. s/m
ζ_p	0.008	

ζ<<1

Appendix F: Characterization of mounts

Measured Natural Response of the System





Calculation of Damping Ratio

node	Point	Time [s]	Amplitude [m.s^{-2}]	Period [s]	log. decr.
1	19	0.140625	0.9448396		
1.5	27	0.203125	-0.825085		
2	35	0.265625	0.8729868	0.125	0.079
2.5	43	0.328125	-0.5528265	0.125	0.400
3	51	0.390625	0.5733558	0.125	0.420
3.5	59	0.453125	-0.3739278	0.125	0.391
4	67	0.515625	0.3866364	0.125	0.394
4.5	75	0.578125	-0.230711	0.125	0.483
5	83	0.640625	0.2561283	0.125	0.412
5.5	90	0.695313	-0.1471271	0.117	0.450
6	98	0.757813	0.1867194	0.117	0.316
6.5	106	0.820313	-0.0992253	0.125	0.394
7	112	0.867188	0.1490823	0.109	0.225
7.5	120	0.929688	-0.0645209	0.109	0.430
8	128	0.992188	0.1138891	0.125	0.269
			avergage	0.121	0.359

f_d	8.24	Hz	
ω_d	51.76	rad/s	
m_e	46.26	kg	
N_m	6	mounts	
c	273.451	N. s/m	
c_{mi}	45.575	N. s/m	
ζ_{mi}	0.057		**ζ<<1**