BIBLIOGRAPHY


NEL, C. 2007. Design analysis of a rubber mount system for a push-type centrifuge. (Paper delivered at the 4th International Congress on Sound and Vibration in Cairns, Australia)


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E. Characterisation of plate pack
F. Characterisation of mounts
Appendix A: Two DOF model without damping

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

clear;
clc;

tel = 330;  
uit = 106  
kies = 1

m1 = 22.255;  
m2 = 24.007;  
M = [m1 0; 0 m2];

kmi = 20718;  
Nm = 6;  
kcl = 36529;  
kp = 319997;

k2 = kp;  
k3 = kcl;  
k1(1) = Nm*kmi+kcl;  
k1(2) = 1000*k2;  
w = zeros(tel,1);

for j = 1:2
    K = [k1(j)+k2 -k2; -k2 k2+k3];
    [V,D] = eig(K,M);
    run = j
    omegal1 = sqrt(D(1,1));  
    f1 = omegal1/(2*pi)
    omegal2 = sqrt(D(2,2));  
    f2 = omegal2/(2*pi)

    for i = 1:tel
        w(i) = i;
        F0(:,i) = [0 ; 0.002238244*w(i)^2];  
        A = (-M*w(i)^2 + K);  
        X = linsolve (A,F0(:,i));
        F1(i,j) = X(1)* k1(j);  
        F2(i,j) = (X(2)-X(1)) * k2;  
        F3(i,j) = X(2) * k3;
        Xi(i,j) = X(1);
        X2(i,j) = X(2);

A-1
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 oscillating 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_u = k1(kies)
k2
k3
m1
m2

F0_u = F0(2,uit)
X1_u = X1(uit,kies)
X2_u = X2(uit,kies)
X1dotdot1_u = -X1_u*uit^2*M(1,1)
X2dotdot2_u = -X2_u*uit^2*M(2,2)
F1_u = F1(uit,kies)
F2_u = F2(uit,kies)
F3_u = F3(uit,kies)
Appendix B: Two DOF model with damping

10/18/11 7:18 PM C:\Users\user\Documents\Magister\Verhadeling\Model...\kragte.m 1 of 2

%Determine forces for 2 DOF system with damping
%Runge Kutta integration

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

%Solution 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(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);
cf;
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);
cf;
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]');
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^2
     (1,1);

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

Appendix C: DEG engineering drawing: Panel bank
301EX-2491 A/B
Appendix D: Design of vibration model
Note: core must be taken that all plates' holes align

0.7mm Plate

Note: To be manufactured by designer.

0.7mm Guide
Appendix E: Characterization of plate pack

*Measured Natural Response of the System*

**Bump test on bolted model, without compensators**

**Bump Test on Bolted Model, without Compensators**
## Calculation of Damping Ratio

<table>
<thead>
<tr>
<th>node</th>
<th>Point</th>
<th>Time [s]</th>
<th>Amplitude [m.s(^{-2})]</th>
<th>Period [s]</th>
<th>log. decr.</th>
</tr>
</thead>
<tbody>
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<td>1.53125</td>
<td>0.6241905</td>
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<td>0.046</td>
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<td>0.044</td>
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<tr>
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<td>0.050</td>
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<tr>
<td>9</td>
<td>253</td>
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<td>0.052</td>
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<tr>
<td></td>
<td>average</td>
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<td></td>
<td></td>
<td>0.055</td>
</tr>
</tbody>
</table>

| 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

<table>
<thead>
<tr>
<th>node</th>
<th>Point</th>
<th>Time [s]</th>
<th>Amplitude [m.s⁻²]</th>
<th>Period [s]</th>
<th>log. decr.</th>
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average 0.121 0.359

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<td>c₁dg</td>
<td>51.76 rad/s</td>
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<tr>
<td>mₙ</td>
<td>46.26 kg</td>
</tr>
<tr>
<td>Nₘₙ</td>
<td>6 mounts</td>
</tr>
<tr>
<td>c</td>
<td>273.451 N.s/m</td>
</tr>
<tr>
<td>c₁cs</td>
<td>45.575 N.s/m</td>
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<tr>
<td>ζₘₙ</td>
<td>0.057 ζ&lt;&lt;1</td>
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