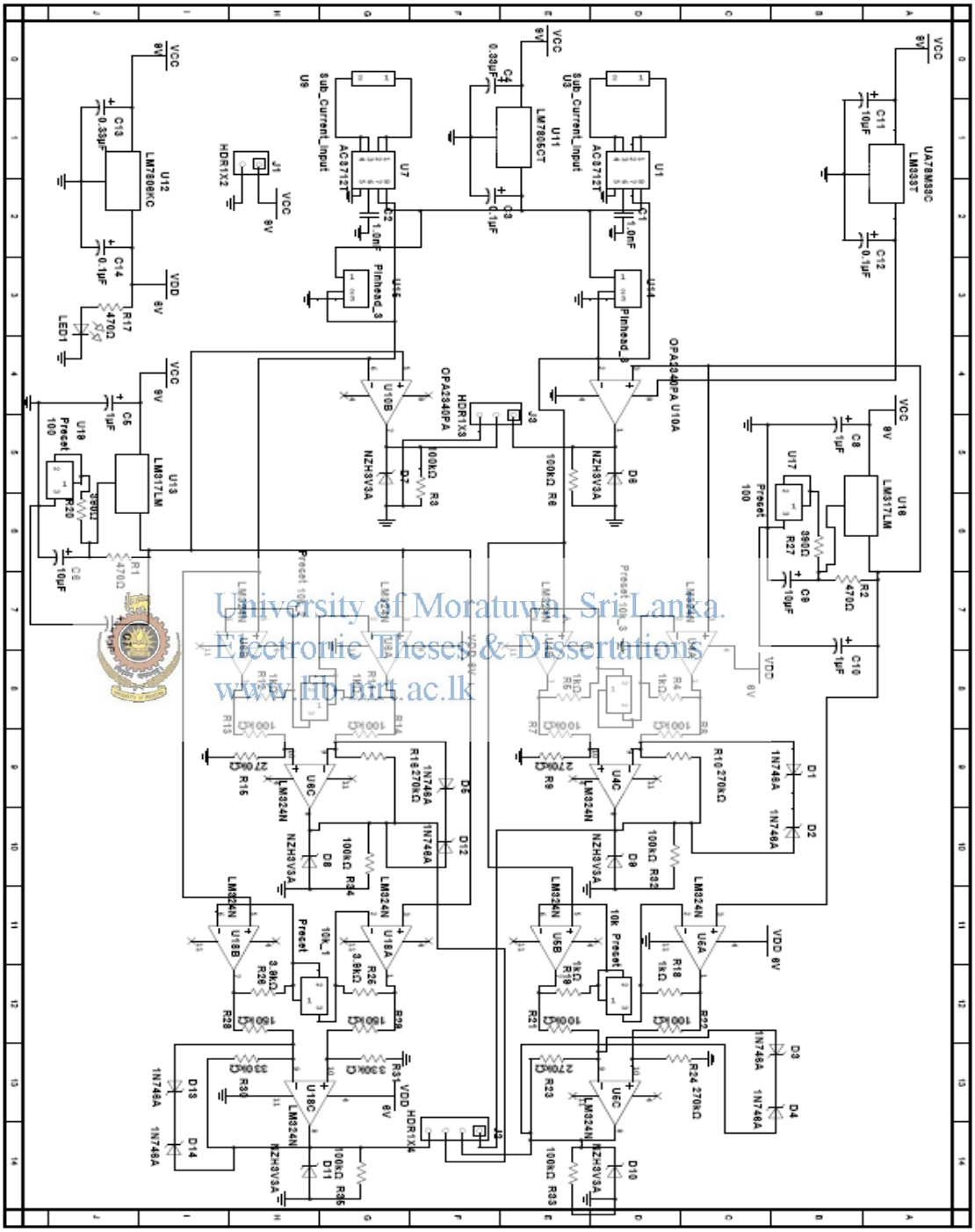
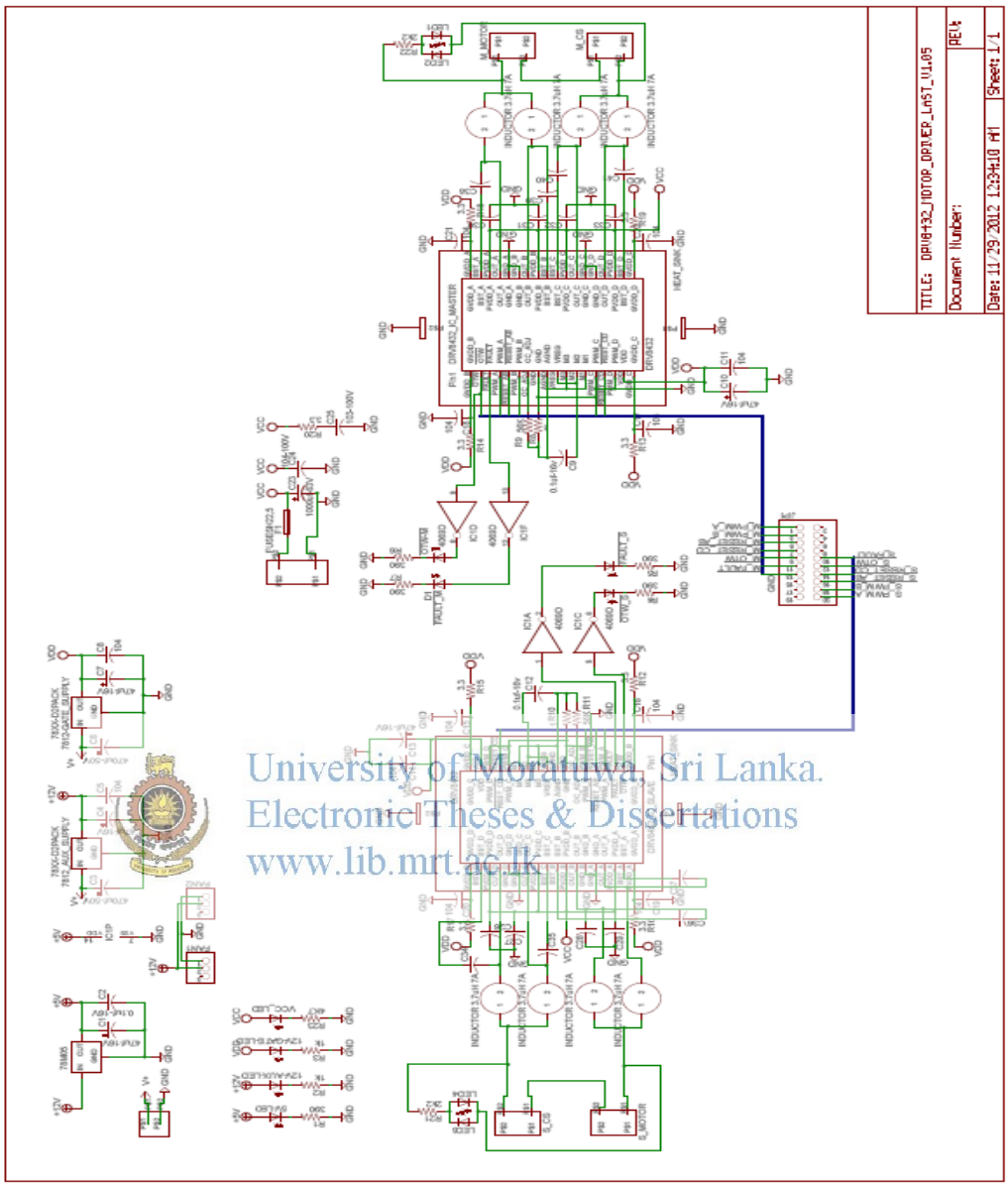
9 APPENDIX

Appendix I



Appendix II



Appendix III

Matlab m code

```
function[x] = virtual_impdance_controller(t)
t=0:0.1:10;
%impedance modal parameters
w=10.0;%0.1,1,5,10,100,1000
m=0.1;
d=1.0;
K=0.0;
k=0.5;
fm=30.0;
fs=0.0;
x=0.0;

%external vibration
K2=10.0;
w2=1;%1000,100,10,5,1,0.1

%pd controller
Kp =80.0;
Kd=1.5;
%motor paramters
Kt=0.5;
Jn=0.009;
Ktn=0.5;

dt=0.1;
dx=0.0;
x_master_res=0.0;
dx_master_res=0.0;
y1=0.0;
x_previous=1.0;
x_master_res_previous=0.0;
y2=0.0;
y6=0.0;
y7=0.0;
J=0.009;
y8=0,0;
y9=0.0;

R_tob_m=0.0;
R_tob_s=0.0;
y10=0.0;
y11=0.0;
y12=0.0;
```

```
y13=0.0;
y_previous=0.0;
y14=0.0;
y14_1=0.0;
y14_previous=0.0;

force_input_master=0.0;%dob input
force_input_slave=0.0;

y15=0.0;
y16=0.0;
y16_previous=0.0;
y17=0.0;
y17_previous=0.0;
temp1=0.0;
temp2=0.0;
g1=50.0;
g2=50.0;
y18=0.0;


z1=0.0;
x_slave_res=0.0;

x_master_res_previous=0.0;
x_slave_res_previous=0.0;
dx_slave_res=0.0;
z2=0.0;
z6=0.0;
z7=0.0;

z8=0,0;
z9=0.0;


z10=0.0;
z11=0.0;
z12=0.0;
z13=0.0;
z_previous=0.0;
z14=0.0;
z14_1=0.0;
z14_previous=0.0;
force_input=0.0;

z15=0.0;
```

```
z16=0.0;
z16_previous=0.0;
z17=0.0;
z17_previous=0.0;
temp3=0.0;
temp4=0.0;
g1=5.0;
g2=50.0;
z18=0.0;

%impedance modal
a =(-d+sqrt(power(d,2)-4*m*k))/2;
b =(-d-sqrt(power(d,2)-4*m*k))/2;
A=K*w/((a-b)*(power(a,2)+power(w,2)));
B=K*w/((b-a)*(power(b,2)+power(w,2)));
D=(K*w+A*b*power(w,2)+B*a*w.^2)/a*b;
 C=(K*w+(1+power(w,2))*(-A*(1+b)+B*(a-1))-D*(1-a)*(1-b))/((1-a)*(1-b));
 E=(fm-R_tob_s)/(a-b);
F=(fm-R_tob_s)/(b-a);
x=exp(a*t)*(A+E)+exp(b*t)*(B+F)+C*cos(w*t)+D*sin(w*t);

%master controller
y1=x-x_master_res;
dx=(x-x_previous)/dt;
x_previous=x;

dx_master_res=(x_master_res-x_master_res_previous)/dt;
x_master_res_previous=x_master_res;

y2=Kp*y1;
y6=(dx-dx_master_res)*Kd;
y7=y2+y6;

y8=y7*J;
y9=y8+R_tob_m;
y10=y9/Kt;


%rtob master
y11=y10*Kt;
y13=y11-force_input_master;

%y14=(y13*dt+y_previous)*1/J;
y14_1=(y13*dt+y_previous);
y14=y14_1*1/J;
y_previous=y14;
```

```
x_master_res=y14*dt+y14_previous;
y14_previous=x_master_res;

y12=y10*Ktn;
y15=y14*Jn*g1;
y16=y12+y15;

y17=y17_previous+g1*(y16-y17)*dt;
y17_previous=y17;


y18=y14*g1*Jn;

R_tob_m=-(y17-y18);



%slave controller


z1=x_master_res-x_slave_res;
dx_slave_res=(x_slave_res-x_slave_res_previous)/dt;
x_slave_res_previous=x_slave_res;

dx_master_res=(x_master_res-x_master_res_previous)/dt;
x_master_res_previous=x_master_res;

z2=Kp*z1;
z6=(dx_master_res-dx_slave_res)*Kd;
z7=z2+z6;

z8=z7*J;
z9=z8+R_tob_s;
z10=z9/Kt;

%rtob slave
z11=z10*Kt;
%z13=z11-force_input_slave;
z13=z11-K2*sin(w*t);
%y14=(y13*dt+y_previous)*1/J;
z14_1=(z13*dt+z_previous);
z14=z14_1*1/J;
z_previous=z14;
```

```
x_slave_res=z14*dt+z14_previous;
z14_previous=x_slave_res;

z12=z10*Ktn;
z15=z14*Jn*g1;
z16=z12+z15;

z17=z17_previous+g1*(z16-z17)*dt;
z17_previous=z17;


z18=z14*g1*Jn;

R_tob_s=z17-z18;
%R_tob_s=fs;



%plot(t,x_master_res,t,x_slave_res);
plot(t,R_tob_m,t,R_tob_s);
%plot(t,y15);
xlabel('time');
ylabel('force');
```

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