Politecnico di Torino

Corso di Laurea Mechanical Engineering
A.a. 2020/2021
Sessione di Laurea Ottobre 2021

Design of a test bench for the flow ripple determination in positive-displacement hydraulic pumps

Annex Matlab code

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```
clear all
clc
T=35; %temperature
f=([290;580;870;1160;1450;1740;2030;2320;2610;2900]); % theorical frequencies
fs=10000; %sampling frequency
%% fluid charactheristics
pho=876; %density
l=0.15; %length
v=30.69; %viscosity
c=1280.82366; %speed of sound
r1=8; %mm
r=8/1000; %internal radius
w=zeros(1,10);
zita=zeros(1,10);
b=zeros(1,10);
jzcd=zeros(1,10);
jzc=zeros(1,10);
rez=zeros(1,10);
imz=zeros(1,10);
for k=1:10
    w(k)=2*pi*290*k;
end
for k=1:10
rez(k)=(1+(sqrt((v/(2*r1^2.*w(k))))));
imz(k)=-(sqrt((v/(2*r1^2.*w(k))))+(v/(r1^2.*w(k))));
zita(k)=complex(rez(k),imz(k));
b(k)=(zita(k).*w(k))/c;
zc(k)=((pho*c).*zita(k))/(pi*r^2);
jzcd(k)=1i/zc(k);
jzc(k)=1i*zc(k);
end
%% now we start computing P0 values
Y1=xlsread('1st1st.xlsx');
Y1=Y1.*(3.125*10^6); %get Pa
N=length(Y1);
time=linspace(0,1,N);
figure (90)
plot(time, Y1,'r','LineWidth',1.5)
set(gca,'FontSize',24)
xlabel('time [s]')
ylabel('pressure [Pa]');
xlim([0,0.015])
minn1=min(Y1);
maxx1=max(Y1);
delta1=(maxx1-minn1)*10^-5; %bar value
means=mean(Y1);
y1=2*fft(Y1,N)/N; %FFT
xx=linspace(0,fs,N)';
figure (1)
stem(xx,abs(y1),'r','LineWidth', 4)
xlim([5,2950])
ylim([0,10e4])
xlabel('frequency [Hertz]')
ylabel('pressure [Pa]');
set(gca,'FontSize',24)
```

```
legend('1st transducer 1st loading valve')
grid on
%% 2nd trans 1st valve
Y2=xlsread('2nd1st.xlsx');
Y2=Y2.*(3.125*10^6);
y2=2*fft(Y2,N)/N; %FFT
figure (2)
stem(xx,abs(y2),'r','LineWidth', 4)
set(gca,'FontSize',24)
xlim([5,2950])
ylim([0,10e4])
xlabel('frequency [Hertz]')
ylabel('pressure [Pa]');
legend('2nd transducer 1st loading valve')
grid on
minn2=min(Y2);
maxx2=max(Y2);
delta2=(maxx2-minn2)*10^-5; %bar value
%% 1st tran 2nd valve
Y3=xlsread('1st2nd.xlsx');
Y3=Y3.*(3.125*10^6);
y3=2*fft(Y3,N)/N; %FFT
figure (3)
stem(xx,abs(y3),'LineWidth', 4)
xlim([5,2950])
ylim([0,10e4])
set(gca,'FontSize',24)
xlabel('frequency [Hertz]')
ylabel('pressure [Pa]');
legend('1st transducer 2nd loading valve')
grid on
minn3=min(Y3);
maxx3=max(Y3);
delta3=(maxx3-minn3)*10^-5; %bar value
%% 2nd 2nd
Y4=xlsread('2nd2nd.xlsx');
Y4=Y4.*(3.125*10^6);
y4=2*fft(Y4,N)/N; %FFT
figure (4)
stem(xx,abs(y4),'LineWidth', 4)
set(gca,'FontSize',24)
xlim([5,2950])
ylim([0,10e4])
xlabel('frequency [Hertz]')
ylabel('pressure [Pa]');
legend('2nd transducer 2nd loading valve')
grid on
minn4=min(Y4);
maxx4=max(Y4);
delta4=(maxx4-minn4)*10^-5; %bar value
%% computation Pressure parameters
zz=0;
fre=zeros(1,10);
rr=0;
index1=0;
p0=zeros(1,10); % vector of complex pression
```

```
value0=zeros(1,10);
pv=complex(0,0); %var
for i=270:290
    if abs(y1(i))>rr
        index1=i;
        rr=abs(y1(i));
    end
end
for i=1:10
    fre(i)=index1*i;
end
for i=1:10
    for k=(fre(i)-15):(fre(i)+15)
        if abs(y1(k))>zz
            zz=abs(y1(k));
            pv=y1(k);
            value0(i)=k;
        else zz=zz;
        end
        p0(i)=pv;
    end
    zz=0;
end
zz=0;
pv=complex(0,0);
%% p1
fre=zeros(1,10);
rr=0;
value1=zeros(1,10);
index2=0;
p1=zeros(1,10); % vector of complex pressure
for i=270:290
   if abs(y2(i))>rr
       index2=i;
       rr=abs(y2(i));
   end
end
for i=1:10
    fre(i)=index2*i;
end
for i=1:10
    for k=(fre(i)-15):(fre(i)+15)
        if abs(y2(k))>zz
            zz=abs(y2(k));
            pv=y2(k);
              value1(i)=k;
        else zz=zz;
        end
        p1(i)=pv;
    end
    zz=0; % end of each loop
end
zz=0;
pv=complex(0,0);
%% p0'
zz=0;
```

```
fre=zeros(1,10);
value2=zeros(1,10);
rr=0;
index3=0;
p00=zeros(1,10); % vector of complex pressure
pv=complex(0,0); %var
for i=270:290
   if abs(y3(i))>rr
       index3=i;
       rr=abs(y3(i));
   end
end
for i=1:10
    fre(i)=index3*i;
end
for i=1:10
    for k=(fre(i)-15):(fre(i)+15)
        if abs(y3(k))>zz
            zz=abs(y3(k));
            pv=y3(k);
            value2(i)=k;
        else zz=zz;
        end
        p00(i)=pv;
    end
    zz=0; % end of each loop
end
zz=0;
pv=complex(0,0);
%% p1'
zz=0;
fre=zeros(1,10);
value3=zeros(1,10);
rr=0;
index4=0;
p01=zeros(1,10); % vector of complex pressure
pv=complex(0,0); %var
for i=270:290
   if abs(y4(i))>rr
       index4=i;
       rr=abs(y4(i));
   end
end
for i=1:10
    fre(i)=index4*i;
end
for i=1:10
    for k=(fre(i)-15):(fre(i)+15)
        if abs(y4(k))>zz
            zz=abs(y4(k));
            pv=y4(k);
            value3(i)=k;
        else zz=zz;
        end
        p01(i)=pv;
    end
```

```
    zz=0; % end of each loop
end
%% Qs and Zs
qs=zeros(1,10);
zs=zeros(1,10);
for k=1:10
    qs(k)=jzcd(k).*(((p0(k)*p01(k))-(p00(k)*p1(k)))/((p0(k)-p00(k))*sin(b(k)*l)));
end
for k=1:10
    zs(k)=jzc(k)*(((p0(k)-p00(k))*sin(b(k)*l))/((p1(k)-p01(k))-((p0(k)-p00(k))*cos(b(k)*l))));
end
figure (5)
bar(f,abs(qs)*10^6,'r','LineWidth',1.5);
xlabel('frequency [Hz]')
ylabel('Qs module [10e-6 m^3/s]')
set(gca,'FontSize',24)
ylim([0,20])
grid on
figure (6)
bar(f,abs(zs),'b','LineWidth', 1.5);
ylim([0,0.5*10^11])
xlabel('frequency [Hz]')
ylabel('Zs module [Pas/m^3]')
set(gca,'FontSize',24)
grid on
%% q(time)
phaseqs=zeros(1,10);
for k=1:10
    phaseqs(k)=angle(qs(k))*180/pi;
end
phasezs=zeros(1,10);
for k=1:10
    phasezs(k)=angle(zs(k))*180/pi;
end
%% QS*
qss=zeros(1,10);
for k=1:10
    qss(k)=((zs(k)./(sqrt(zs(k).^2-zc(k).^2))).*qs(k));
end
figure (7)
bar(f,abs(qss)*10^6,'r','LineWidth', 1.5)
xlabel('frequency [Hz]')
ylabel('Qs* module [10e-6 m^3/s]')
ylim([0,20])
set(gca,'FontSize',24)
grid on
phaseqss=zeros(1,10);
for k=1:10
    phaseqss(k)=angle(qss(k))*180/pi;
end

%% q(t) in time
tout=4/290;
x=linspace(0,tout,10000);
y=linspace(0,0,10000);
for t=1:10000
```

```
    for k=1:10
        y(t)=y(t)+(abs(qss(k))*10^6*(cos((2*pi*f(k)*x(t))+phaseqss(k))));
    end
end
figure (8)
plot(x,y,'r','LineWidth', 2)
set(gca,'FontSize',24)
xlabel('time[s]')
ylabel('q(t)*[10e-6 m^3/s]')
ylim([-25,+25])
hold on
kk=x(1566); %starting of the cycle
qmax=16;
fii=linspace(-pi/12,pi/12,1000)';
k=(543030.59*10^-6)*60;
yyy=-248.0573+2.1093+(qmax-k.*(fii.^2))/60*10^3;
xxx=linspace(kk,1/290+kk,1000)';
xxx1=linspace(1/290+kk,2/290+kk,1000)';
xxx2=linspace(2/290+kk,3/290+kk,1000)';
plot(xxx,yyy,'b','LineWidth', 2)
ylim([-25,+25])
hold on
plot(xxx1,yyy,'b','LineWidth', 2)
ylim([-25,+25])
hold on
plot(xxx2,yyy,'b','LineWidth',2)
ylim([-25,+25])
grid on
legend('experimental flow ripple','mathematical model')
%% blocked pressure
pb=zeros(1,10);
for k=1:10
    pb(k)=zs(k)*qs(k);
end
figure (9)
bar(f,abs(pb)*10^-5,'r','LineWidth', 1.5);
set(gca,'FontSize',24)
xlabel('frequency[Hz]')
ylabel('blocked pressure module[bar]')
ylim([0,5.5])
grid on
%% lumped parameter model
c1=0;
for k=1:10
    c1=c1+imag(zs(k)*f(k));
end
c1=c1/10;
zsml=zeros(1,10);
for k=1:10
    zsml(k)=c1/complex(0,f(k));
end
%% lumped
c11=0;
for k=1:10
    c11=c11+abs(imag(zs(k)*f(k)));
end
```

```
c11=c11/10;
zsmla=zeros(1,10);
for k=1:10
    zsmla(k)=c11/complex(0,f(k));
end
figure (10)
bar(f,phaseqs,'r','LineWidth', 1.5)
set(gca,'FontSize',24)
xlabel('frequency [Hz]')
ylabel('qs phase [deg]')
figure (11)
bar(f,phasezs,'r','LineWidth', 1.5)
set(gca,'FontSize',24)
xlabel('frequency [Hz]')
ylabel('zs phase [deg]')
grid on
%% qs and zs verification
qov=zeros(1,10);
p1v=zeros(1,10);
for k=1:10
   qov(k)=qs(k)-(p0(k)/zs(k));
end
for k=1:10
    p1v(k)=(cos(b(k)*l)*p0(k))-(jzc(k)*sin(b(k)*l).*qov(k));
end
error=zeros(1,10);
for k=1:10
    error(k)=(abs(p1(k))-abs(p1v(k)))/abs(p1(k))*100;
end
figure (12)
pression1=[p1;p1v]';
bar(f,abs(pression1),'LineWidth',1.5)
set(gca,'FontSize',24)
legend('p1 computed','p1 experimental')
grid on
%% distrubeted parameter
c2=pi/(2*2030)
c1=(zs(3)+zs(4))/2
bb=0.7 %correction factor
alfa=zeros(1,10);
sigma1=zeros(1,10);
sigma2=zeros(1,10);
j=complex(0,1);
t1=0;
t2=0;
s11=0;
s12=0;
s21=0;
s22=0;
for k=1:100
for i=1:10
    alfa(i)=(j*zs(i)*sin(f(i)*c2))-(c1*cos(f(i)*c2));
    sigma1(i)=-cos(f(i)*c2);
    sigma2(i)=(j*zs(i)*f(i)*cos(f(i)*c2))+(f(i)*c1*sin(f(i)*c2));
    t1=t1+real(alfa(i)*conj(sigma1(i)));
    t2=t2+real(alfa(i)*conj(sigma2(i)));
```

```
    s11=s11+real(conj(sigma1(i))*sigma1(i));
    s12=s12+real(conj(sigma1(i))*sigma2(i));
    s21=s21+real(conj(sigma2(i))*sigma1(i));
    s22=s22+real(conj(sigma2(i))*sigma2(i));
end
deltac1=((t2*s12)-(t1*s22))/((s11*s22)-(s21*s12));
deltac2=((t1*s21)-(t2*s11))/((s11*s22)-(s21*s12));
if abs(deltac1)<=(c1*10^-3) | abs(deltac2)<=(c2*10^-3)
    c1=c1;
    c2=c2;
    k=100
else
    c1=c1+(bb*deltac1);
    c2=c2+(bb*deltac2);

end
end
zsmd=zeros(1,10);
for i=1:10
    zsmd(i)=c1/(j*tan(c2*f(i)));
end
figure (13)
loglog(f,abs(zsmd),'b',f,abs(zs),'x','LineWidth',2)
ylim([0,3.5*10^11])
hold on
loglog(f,abs(zsml),'r','LineWidth', 2)
ylim([0,3.5*10^11])
legend('distributed parameter','experimental','lumped parameter')
set(gca,'FontSize',24)
xlabel('frequency [Hz]')
ylabel('Zs module [Pas/m^3]')
ylim([0,3.5*10^11])
grid on
%% pb rms
pbrms=0;
for i=1:10
    pbrms=pbrms+abs(pb(i))^2;
end
pbrms=sqrt(pbrms/2);
pbrms*10^-5;
```