问题二

（1）附录 2.1

计算单级杆泵功图的 Matlab 程序：

```
function [U,F]=jianmo12sudu
x=792.5;
Uo=[0.0000  0.0040  0.0120  0.0230  0.0370  0.0540  0.0740  0.0970  0.1230
0.1520  0.1830  0.2160  0.2510  0.2890  0.3280  0.3690  0.4120  0.4560
0.5010  0.5480  0.5960  0.6450  0.6940  0.7450  0.7970  0.8490  0.9010
0.9540  1.0080  1.0620  1.1160  1.1700  1.2250  1.2790  1.3340  1.3880
1.4420  1.4960  1.5500  1.6030  1.6550  1.7070  1.7580  1.8080  1.8580
1.9060  1.9530  1.9990  2.0430  2.0860  2.1270  2.1670  2.2050  2.2410
2.2750  2.3070  2.3370  2.3650  2.3910  2.4140  2.4350  2.4540  2.4710
2.4850  2.4970  2.5070  2.5150  2.5200  2.5240  2.5250  2.5240  2.5220
2.5180  2.5120  2.5040  2.4950  2.4840  2.4720  2.4590  2.4440  2.4270
2.4100  2.3910  2.3720  2.3510  2.3290  2.3050  2.2810  2.2560  2.2290
2.2010  2.1720  2.1420  2.1110  2.0790  2.0460  2.0110  1.9750  1.9380
1.9000  1.8600  1.8200  1.7780  1.7350  1.6900  1.6450  1.5980  1.5500
1.5010  1.4510  1.3990  1.3470  1.2940  1.2390  1.1840  1.1290  1.0720
1.0150  0.9580  0.9010  0.8440  0.7860  0.7290  0.6730  0.6180  0.5630
0.5100  0.4590  0.4090  0.3610  0.3150  0.2720  0.2310  0.1930  0.1580
0.1270  0.0980  0.0740  0.0520  0.0340  0.0200  0.0100  0.0030  0.0000 ];
D=[28.5460  31.1600  33.2510  35.4120  37.9570  40.7800  46.1480  50.4000  53.9900
55.9420  56.8830  57.0920  57.5450  58.1030  58.1380  58.2420  58.3470  58.0680
58.0680  58.2420  58.6610  58.9050  59.4620  60.0200  60.8910  61.2050  61.3440
60.8910  61.2750  61.0660  60.7520  59.8110  59.4970  58.8700  58.0330  57.6150
57.2320  56.4650  55.5240  55.0360  54.4080  53.9550  53.5020  53.5370  53.0490
53.2230  52.7000  52.2470  52.1780  52.2470  51.4810  50.7830  50.3300  49.8070
49.0410  48.2740  47.2980  46.7400  45.8340  45.5900  45.2070  44.9630  44.6840
44.4050  44.1960  43.9170  43.6030  43.1150  42.7320  41.9650  40.8500  40.2570
39.7000  39.6650  39.6650  38.1310  31.8220  30.1840  28.3720  27.0470  26.3850
23.8060  19.1700  16.7650  14.9880  13.2450  11.8850  14.2210  17.1140  19.6930
20.8080  22.4460  23.4220  21.0870  18.9960  16.4510  15.5450  13.6980  13.0010
14.4650  16.2770  18.1590  17.1830  17.3230  17.2880  16.5210  15.3710  14.7090
15.0570  14.4300  14.2560  14.3600  14.5340  14.7090  14.8830  14.7780  14.8130
14.7090  14.9530  15.2660  15.4060  15.3010  15.5100  16.2420  16.7300  17.2530
17.6710  18.6120  19.0310  19.3440  20.1460  20.8080  21.7840  21.9590  22.6900
23.2130  23.4920  23.3530  23.3880  23.8060  24.1200  24.5380  24.8860  25.3390 ];
D=D*1000;
f=7.6; %f  为冲次
w=f/60*2*pi();
t=[ 0.0000    0.0572  0.1144  0.1716  0.2288  0.2860  0.3432  0.4005  0.4577
0.5149  0.5721  0.6293  0.6865  0.7437  0.8009  0.8581  0.9153  0.9725
1.0297  1.0870  1.1442  1.2014  1.2586  1.3158  1.3730  1.4302  1.4874
```

```
1.5446  1.6018  1.6590  1.7162  1.7735  1.8307  1.8879  1.9451  2.0023
2.0595  2.1167  2.1739  2.2311  2.2883  2.3455  2.4027  2.4600  2.5172
2.5744  2.6316  2.6888  2.7460  2.8032  2.8604  2.9176  2.9748  3.0320
3.0892  3.1465  3.2037  3.2609  3.3181  3.3753  3.4325  3.4897  3.5469
3.6041  3.6613  3.7185  3.7757  3.8330  3.8902  3.9474  4.0007  4.0541
4.1074  4.1607  4.2141  4.2674  4.3208  4.3741  4.4275  4.4808  4.5341
4.5875  4.6408  4.6942  4.7475  4.8009  4.8542  4.9075  4.9609  5.0142
5.0676  5.1209  5.1743  5.2276  5.2809  5.3343  5.3876  5.4410  5.4943
5.5477  5.6010  5.6543  5.7077  5.7610  5.8144  5.8677  5.9211  5.9744
6.0277  6.0811  6.1344  6.1878  6.2411  6.2945  6.3478  6.4011  6.4545
6.5078  6.5612  6.6145  6.6679  6.7212  6.7745  6.8279  6.8812  6.9346
6.9879  7.0413  7.0946  7.1479  7.2013  7.2546  7.3080  7.3613  7.4147
7.4680  7.5213  7.5747  7.6280  7.6814  7.7347  7.7881  7.8414  7.8947 ];
k=length(D);
d=22;%抽油杆直径
Ar=1/4*pi()*(d/1000)^2;
g=9.8;
L=792.5;
roul=846*(1-0.98)+1000*0.98;
roug=8456;
Wrr=(roug-roul)*g*Ar*L;
    for p=1:k
        D(p)=D(p)-Wrr;
    end                                                    %第一步
a=4860;    %声速 m/s
N=10;       %傅里叶级数所取的项数
oo=linspace(0,0,N);yy=linspace(0,0,N);tt=linspace(0,0,N);dd=linspace(0,0,N);
aa=linspace(0,0,N);bb=linspace(0,0,N);K=linspace(0,0,N);O=linspace(0,0,N);
P=linspace(0,0,N);OO=linspace(0,0,N);PP=linspace(0,0,N);u=linspace(0,0,N);
OP=linspace(0,0,k);OOPP=linspace(0,0,k);U=linspace(0,0,k);F=linspace(0,0,k);
cd=0;v=0;  %傅里叶系数初始化
oo0=0;yy0=0;
E=2.1*10^11;
for p=1:k;
oo0=2/k*D(p)*cos(2*pi()*0*p/k)+oo0;
end
for p=1:k;
yy0=2/k*Uo(p)*cos(2*pi()*0*p/k)+yy0;
end
for n=1:N
for p=1:k
     oo(n)=2/k*D(p)*cos(2*pi()*n*p/k)+oo(n);
end
end
```

```
for n=1:N
for p=1:k
    tt(n)=2/k*D(p)*sin(2*pi()*n*p/k)+tt(n);
end
end
for n=1:N
for p=1:k
    yy(n)=2/k*Uo(p)*cos(2*pi()*n*p/k)+yy(n);
end
end
for n=1:N
for p=1:k
    dd(n)=2/k*Uo(p)*sin(2*pi()*n*p/k)+dd(n);
end
end
for i=1:k
v=(4315/2495*w*950/1000*sin(w*t(i)))^2+v; %加和 除以点数
end
v=(v/k)^0.5;
if   v==0.10194737
cd=0.499612;
     elseif v==0.304317197
cd=0.170975;
     elseif v==0.457011024
cd=0.142155;
     elseif v<0.10194737
cd=-2361.8*v^3 + 651.9*v^2 - 65.333*v + 2.8838 ;
     elseif v>0.10194737 && v<0.304317197
cd=-38.609*v^3 + 31.455*v^2 - 9.2174*v + 1.1485   ;
     elseif v>0.304317197 && v<0.457011024
cd=-0.286*v^3 + 1.2491*v^2 - 1.0164*v + 0.3729;
elseif v>0.457011024
cd=0.14;
end
%光杆速度及无因此阻尼系数因子，拟合曲线数据
c=pi()*a*cd/2/L;
 %s^-1                                                    %第二步
for n=1:N
    aa(n)=n*w/a/2^0.5*(1+(1+(c/n/w)^2)^0.5)^0.5;
end
for n=1:N
    bb(n)=n*w/a/2^0.5*(-1+(1+(c/n/w)^2)^0.5)^0.5;
end                                                      %  第三步
for n=1:N
```

```
        K(n)=(oo(n)*aa(n)+tt(n)*bb(n))/(aa(n)^2+bb(n)^2)/E/Ar;
    end
    for n=1:N
        u(n)=(oo(n)*aa(n)-tt(n)*bb(n))/(aa(n)^2+bb(n)^2)/E/Ar;
    end                                                          %第四步
    for n=1:N
        O(n)=(K(n)*cosh(bb(n)*x)+dd(n)*sinh(bb(n)*x))*sin(aa(n)*x)+(u(n)*...
        sinh(bb(n)*x)+yy(n)*cosh(bb(n)*x))*cos(aa(n)*x);
    end
    for n=1:N
        P(n)=(K(n)*sinh(bb(n)*x)+dd(n)*cosh(bb(n)*x))*cos(aa(n)*x)-(u(n)*...
        cosh(bb(n)*x)+yy(n)*sinh(bb(n)*x))*sin(aa(n)*x);
    end
    for n=1:N
        OO(n)=(tt(n)/E/Ar*sinh(bb(n)*x)+(dd(n)*bb(n)-yy(n)*aa(n))*...
        cosh(bb(n)*x))*sin(aa(n)*x)+(oo(n)/E/Ar*cosh(bb(n)*x)+...
    (yy(n)*bb(n)+dd(n)*aa(n))*sinh(bb(n)*x))*cos(aa(n)*x);
    end
    for n=1:N
        PP(n)=(tt(n)/E/Ar*cosh(bb(n)*x)+(dd(n)*bb(n)-yy(n)*aa(n))*...
        sinh(bb(n)*x))*cos(aa(n)*x)-(oo(n)/E/Ar*sinh(bb(n)*x)+(yy(n)*...
    bb(n)+dd(n)*aa(n))*cosh(bb(n)*x))*sin(aa(n)*x);
    end
    for i=1:k
        for n=1:N
        OP(i)=O(n)*cos(n*w*t(i))+P(n)*sin(n*w*t(i))+OP(i);
        end
    end
    for i=1:k
        for n=1:N
        OOPP(i)=OO(n)*cos(n*w*t(i))+PP(n)*sin(n*w*t(i))+OOPP(i);
        end
    end
    for i=1:k
    U(i)=oo0/2/E/Ar*x+yy0/2+OP(i);
    end
    for i=1:k
    F(i)=oo0/2+E*Ar*OOPP(i);
    end
    F=F/1000;
    end
```

（2）附录 2.2

计算多级杆泵示功图的 **Matlab** 程序：

```
function [U,F,D]=jianmo22suduxilie03
Uo=[0 0 0.01 0.02 0.04 0.07 0.1 0.14 0.18 0.23 0.28 0.34 0.4 0.47 0.53 0.61 0.68
0.76 0.84 0.92 1.01 1.09 1.18 1.27 1.36 1.46 1.55 1.65 1.74 1.84 1.93 2.03 2.12 2.22 2.31
2.41 2.5 2.6 2.69 2.78 2.87 2.96 3.05 3.14 3.22 3.31 3.39 3.47 3.55 3.63 3.71 3.78 3.85
3.92 3.99 4.06 4.12 4.18 4.24 4.3 4.35 4.4 4.45 4.49 4.54 4.58 4.61 4.65 4.68 4.71 4.73
4.76 4.77 4.79 4.79 4.8 4.8 4.8 4.79 4.77 4.75 4.73 4.7 4.67 4.63 4.58 4.53 4.48 4.42
4.35 4.29 4.21 4.14 4.05 3.97 3.89 3.8 3.71 3.61 3.52 3.42 3.32 3.22 3.12 3.01 2.91 2.8 2.7
2.59 2.48 2.37 2.26 2.16 2.05 1.94 1.84 1.73 1.63 1.53 1.43 1.33 1.23 1.14 1.05 0.96 0.87
0.79 0.71 0.63 0.55 0.48 0.42 0.35 0.3 0.24 0.19 0.15 0.11 0.08 0.05 0.03 0.01 0];
D=[48.6150.01 52.84 52.98 53.2 53.56 53.42 52.77 55.46 57.08
59.02 60.67 61.46 62.28 63.07 64.4 67.2 69.78 71.94 74.2 75.21
76.68 76.64 74.42 71.87 70.04 68.67 67.49 67.42 67.45
68.89 70.97 72.58 73.05 73.23 72.87 72.08 70.9 69.96 68.1
67.31 67.63 68.24 68.42 69.17 70.5 71.26 71.47 71.01 70.29
69.53 68.85 68.17 67.99 67.63 67.88 68.6 69.21 69.75 69.78
70.04 70.07 69.64 69.03 68.28 67.77 67.31 67.27 67.38
67.74 68.13 68.6 68.71 68.67 68.17 67.85 67.31 66.81 65.73
65.15 64.72 63.61 63.25 62.82 62.57 62.46 62.68 62.5 61.71
60.92 59.45 58.19 56.97 55.1 53.59 51.55 49.83 47.46 44.73
42.25 39.63 38.98 40.6 43.44 45.48 47.24 48.78 49.68 49.75
49.07 47.31 44.73 43.22 42.43 42.29 42.5 43.47 45.55 46.13
47.74 48.25 48.07 47.53 46.49 45.27 44.58 43.76 43.65
44.05 44.87 46.06 46.67 48.14 48.53 48.5 48.14 47.96 47.35
46.85 46.99 46.67 46.81 47.46];
D=D*1000;
f=4; %f 为冲次
w=f/60*2*pi();
t=[0 0.105633803 0.211267606 0.316901408 0.422535211 0.528169014 0.633802817
0.73943662 0.845070423 0.950704225 1.056338028 1.161971831 1.267605634
1.373239437 1.478873239 1.584507042 1.690140845 1.795774648 1.901408451
2.007042254 2.112676056 2.218309859 2.323943662 2.429577465 2.535211268
2.64084507 2.746478873 2.852112676 2.957746479 3.063380282 3.169014085
3.274647887 3.38028169 3.485915493 3.591549296 3.697183099 3.802816901
3.908450704 4.014084507 4.11971831 4.225352113 4.330985915 4.436619718
4.542253521 4.647887324 4.753521127 4.85915493 4.964788732 5.070422535
5.176056338 5.281690141 5.387323944 5.492957746 5.598591549 5.704225352
5.809859155 5.915492958 6.021126761 6.126760563 6.232394366 6.338028169
6.443661972 6.549295775 6.654929577 6.76056338 6.866197183 6.971830986
7.077464789 7.183098592 7.288732394 7.394366197 7.5 7.605633803 7.711267606
7.816901408 7.922535211 8.028169014 8.133802817 8.23943662 8.345070423
8.450704225 8.556338028 8.661971831 8.767605634 8.873239437 8.978873239
9.084507042 9.190140845 9.295774648 9.401408451 9.507042254 9.612676056
9.718309859 9.823943662 9.929577465 10.03521127 10.14084507 10.24647887
```

```
10.35211268  10.45774648  10.56338028  10.66901408  10.77464789  10.88028169
10.98591549  11.0915493   11.1971831   11.3028169   11.4084507   11.51408451
11.61971831  11.72535211  11.83098592  11.93661972  12.04225352  12.14788732
12.25352113  12.35915493  12.46478873  12.57042254  12.67605634  12.78169014
12.88732394  12.99295775  13.09859155  13.20422535  13.30985915  13.41549296
13.52112676  13.62676056  13.73239437  13.83802817  13.94366197  14.04929577
14.15492958  14.26056338  14.36619718  14.47183099  14.57746479  14.68309859
14.78873239  14.8943662   15];
k=length(D);
d= [25 22 19];%抽油杆直径
Ar=[0 0 0];
Ar(1)=1/4*pi()*(d(1)/1000)^2;Ar(2)=1/4*pi()*(d(2)/1000)^2;Ar(3)=1/4*pi()*(d(3)/1000)^2;
g=9.8;
L=[523.61 664.32 618.35];
roul=846*(1-0.912)+1000*0.912;
roug=8456;Wrr=[0 0 0 0];
Wrr(1)=(roug-roul)*g*(Ar(1)*L(1)+Ar(2)*L(2)+Ar(3)*L(3));
Wrr(2)=(roug-roul)*g*(Ar(2)*L(2)+Ar(3)*L(3));
Wrr(3)=(roug-roul)*g*Ar(3)*L(3);
Wrr(4)=0;
    for p=1:k
        D(p)=D(p)-Wrr(1);
    End                                                    %第一步
a=4860;    %声速 m/s
N=10;       %傅里叶级数所取的项数
oo=linspace(0,0,N);yy=linspace(0,0,N);tt=linspace(0,0,N);dd=linspace(0,0,N);
aa=linspace(0,0,N);bb=linspace(0,0,N);K=linspace(0,0,N);O=linspace(0,0,N);
P=linspace(0,0,N);OO=linspace(0,0,N);PP=linspace(0,0,N);u=linspace(0,0,N);
OP=linspace(0,0,k);OOPP=linspace(0,0,k);U=linspace(0,0,k);F=linspace(0,0,k);
cd=0;v=0;  %傅里叶系数初始化
oo0=0;yy0=0;
E=2.1*10^11;
for p=1:k;
oo0=2/k*D(p)*cos(2*pi()*0*p/k)+oo0;
end
for p=1:k;
yy0=2/k*Uo(p)*cos(2*pi()*0*p/k)+yy0;
end
for n=1:N
for p=1:k
     oo(n)=2/k*D(p)*cos(2*pi()*n*p/k)+oo(n);
end
end
for n=1:N
```

```
for p=1:k
    tt(n)=2/k*D(p)*sin(2*pi()*n*p/k)+tt(n);
end
end
for n=1:N
for p=1:k
    yy(n)=2/k*Uo(p)*cos(2*pi()*n*p/k)+yy(n);
end
end
for n=1:N
for p=1:k
    dd(n)=2/k*Uo(p)*sin(2*pi()*n*p/k)+dd(n);
end
end
for i=1:k
v=(4315/2495*w*950/1000*sin(w*t(i)))^2+v; %加和除以点数
end
v=(v/k)^0.5;
     if    v==0.10194737
cd=0.499612;
     elseif v==0.304317197
cd=0.170975;
     elseif v==0.457011024
cd=0.142155;
     elseif v<0.10194737
cd=-2361.8*v^3 + 651.9*v^2 - 65.333*v + 2.8838 ;
     elseif v>0.10194737 && v<0.304317197
cd=-38.609*v^3 + 31.455*v^2 - 9.2174*v + 1.1485    ;
     elseif v>0.304317197 && v<0.457011024
cd=-0.286*v^3 + 1.2491*v^2 - 1.0164*v + 0.3729;
     elseif v>0.457011024
cd=0.14;
     end
%光杆速度及无因此阻尼系数因子，拟合曲线数据
c=pi()*a*cd/2/(L(1)+L(2)+L(3));
 %s^-1    %                                                    第二步
for n=1:N
    aa(n)=n*w/a/2^0.5*(1+(1+(c/n/w)^2)^0.5)^0.5;
end
for n=1:N
    bb(n)=n*w/a/2^0.5*(-1+(1+(c/n/w)^2)^0.5)^0.5;
end
 z=1;%                                                     第三步
for n=1:N
```

```
    K(n)=(oo(n)*aa(n)+tt(n)*bb(n))/(aa(n)^2+bb(n)^2)/E/Ar(z);
end
for n=1:N
    u(n)=(oo(n)*aa(n)-tt(n)*bb(n))/(aa(n)^2+bb(n)^2)/E/Ar(z);
end                                                          %第四步
for n=1:N
O(n)=(K(n)*cosh(bb(n)*L(z))+dd(n)*sinh(bb(n)*L(z)))*sin(aa(n)*L(z))+(u(n)*...
    sinh(bb(n)*L(z))+yy(n)*cosh(bb(n)*L(z)))*cos(aa(n)*L(z));
end
for n=1:N
    P(n)=(K(n)*sinh(bb(n)*L(z))+dd(n)*cosh(bb(n)*L(z)))*cos(aa(n)*L(z))-(u(n)*...
    cosh(bb(n)*L(z))+yy(n)*sinh(bb(n)*L(z)))*sin(aa(n)*L(z));
end
for n=1:N
    OO(n)=(tt(n)/E/Ar(z)*sinh(bb(n)*L(z))+(dd(n)*bb(n)-yy(n)*aa(n))*...
    cosh(bb(n)*L(z)))*sin(aa(n)*L(z))+(oo(n)/E/Ar(z)*cosh(bb(n)*L(z))+...
(yy(n)*bb(n)+dd(n)*aa(n))*sinh(bb(n)*L(z)))*cos(aa(n)*L(z));
end
for n=1:N
    PP(n)=(tt(n)/E/Ar(z)*cosh(bb(n)*L(z))+(dd(n)*bb(n)-yy(n)*aa(n))*...
    sinh(bb(n)*L(z)))*cos(aa(n)*L(z))-(oo(n)/E/Ar(z)*sinh(bb(n)*L(z))+(yy(n)*...
bb(n)+dd(n)*aa(n))*cosh(bb(n)*L(z)))*sin(aa(n)*L(z));
end
oo0=oo0+0;
yy0=oo0/E/Ar(z)*L(z)+yy0;
for n=1:N
    oo(n)=E*Ar(z)*OO(n);
end
for n=1:N
    tt(n)=E*Ar(z)*PP(n);
end
for n=1:N
    yy(n)=O(n);
end
for n=1:N
    dd(n)=P(n);
end
z=2;
for n=1:N
    K(n)=(oo(n)*aa(n)+tt(n)*bb(n))/(aa(n)^2+bb(n)^2)/E/Ar(z);
end
for n=1:N
    u(n)=(oo(n)*aa(n)-tt(n)*bb(n))/(aa(n)^2+bb(n)^2)/E/Ar(z);
end
```

```
for n=1:N
O(n)=(K(n)*cosh(bb(n)*L(z))+dd(n)*sinh(bb(n)*L(z)))*sin(aa(n)*L(z))+(u(n)*...
    sinh(bb(n)*L(z))+yy(n)*cosh(bb(n)*L(z)))*cos(aa(n)*L(z));
end
for n=1:N
    P(n)=(K(n)*sinh(bb(n)*L(z))+dd(n)*cosh(bb(n)*L(z)))*cos(aa(n)*L(z))-(u(n)*...
    cosh(bb(n)*L(z))+yy(n)*sinh(bb(n)*L(z)))*sin(aa(n)*L(z));
end
for n=1:N
    OO(n)=(tt(n)/E/Ar(z)*sinh(bb(n)*L(z))+(dd(n)*bb(n)-yy(n)*aa(n))*...
    cosh(bb(n)*L(z)))*sin(aa(n)*L(z))+(oo(n)/E/Ar(z)*cosh(bb(n)*L(z))+...
(yy(n)*bb(n)+dd(n)*aa(n))*sinh(bb(n)*L(z)))*cos(aa(n)*L(z));
end
for n=1:N
    PP(n)=(tt(n)/E/Ar(z)*cosh(bb(n)*L(z))+(dd(n)*bb(n)-yy(n)*aa(n))*...
    sinh(bb(n)*L(z)))*cos(aa(n)*L(z))-(oo(n)/E/Ar(z)*sinh(bb(n)*L(z))+(yy(n)*...
bb(n)+dd(n)*aa(n))*cosh(bb(n)*L(z)))*sin(aa(n)*L(z));
end
oo0=oo0+0;
yy0=oo0/E/Ar(z)*L(z)+yy0;
for n=1:N
    oo(n)=E*Ar(z)*OO(n);
end
for n=1:N
    tt(n)=E*Ar(z)*PP(n);
end
for n=1:N
    yy(n)=O(n);
end
for n=1:N
    dd(n)=P(n);
end
z=3;
for n=1:N
    K(n)=(oo(n)*aa(n)+tt(n)*bb(n))/(aa(n)^2+bb(n)^2)/E/Ar(z);
end
for n=1:N
    u(n)=(oo(n)*aa(n)-tt(n)*bb(n))/(aa(n)^2+bb(n)^2)/E/Ar(z);
end
for n=1:N
O(n)=(K(n)*cosh(bb(n)*L(z))+dd(n)*sinh(bb(n)*L(z)))*sin(aa(n)*L(z))+(u(n)*...
    sinh(bb(n)*L(z))+yy(n)*cosh(bb(n)*L(z)))*cos(aa(n)*L(z));
end
for n=1:N
```

```
    P(n)=(K(n)*sinh(bb(n)*L(z))+dd(n)*cosh(bb(n)*L(z)))*cos(aa(n)*L(z))-(u(n)*...
    cosh(bb(n)*L(z))+yy(n)*sinh(bb(n)*L(z)))*sin(aa(n)*L(z));
end
for n=1:N
    OO(n)=(tt(n)/E/Ar(z)*sinh(bb(n)*L(z))+(dd(n)*bb(n)-yy(n)*aa(n))*...
    cosh(bb(n)*L(z)))*sin(aa(n)*L(z))+(oo(n)/E/Ar(z)*cosh(bb(n)*L(z))+...
(yy(n)*bb(n)+dd(n)*aa(n))*sinh(bb(n)*L(z)))*cos(aa(n)*L(z));
end
for n=1:N
    PP(n)=(tt(n)/E/Ar(z)*cosh(bb(n)*L(z))+(dd(n)*bb(n)-yy(n)*aa(n))*...
    sinh(bb(n)*L(z)))*cos(aa(n)*L(z))-(oo(n)/E/Ar(z)*sinh(bb(n)*L(z))+(yy(n)*...
bb(n)+dd(n)*aa(n))*cosh(bb(n)*L(z)))*sin(aa(n)*L(z));
end
for i=1:k
    for n=1:N
    OP(i)=O(n)*cos(n*w*t(i))+P(n)*sin(n*w*t(i))+OP(i);
    end
end
for i=1:k
    for n=1:N
    OOPP(i)=OO(n)*cos(n*w*t(i))+PP(n)*sin(n*w*t(i))+OOPP(i);
    end
end
for i=1:k
U(i)=oo0/2/E/Ar(z)*L(z)+yy0/2+OP(i);
end
for i=1:k
F(i)=oo0/2+E*Ar(z)*OOPP(i);
end
for i=1:k
F(i)=F(i)/1000;
end
  end
```

问题三

(1)附录 3.1

求曲率变化量的 matlab 算法：

```
clear; clc;
%假设 data 是 n 行*2 列的矩阵,n 等于点的个数,
%第一列表示横坐标 xi,第二列表示纵坐标 yi
%点的次序按照逆时针排列
```

```
sum=0;
data=[0.1046834330.13534769  0.173583366  0.217076824  0.263398014  0.310294211
0.35594491  0.39921363  0.43943019  0.47681891  0.512070368  0.546232171
0.580490768  0.615960864  0.653516524  0.693687768  0.73663239  0.782178063
0.829917079  0.879415396  0.929984044  0.981292296  1.033074144  1.085214932
1.137710316  1.190598095  1.243883795  1.297481247  1.351184806  1.40468154
1.45760149  1.509684324  1.560502052  1.61007607  1.658549256  1.706270087
1.753736391  1.801498405  1.850038527  1.899651321  1.950348747  2.001811842
2.053401777  2.104319627  2.15337494  2.199675183  2.24242376  2.281141514
2.315748986  2.346583558  2.374347528  2.399995637  2.424581327  2.449088154
2.474274823  2.50060609  2.52800683  2.556141163  2.58429294  2.611516202
2.636763052  2.65901048  2.677365421  2.691133853  2.699848673  2.703260285
2.701301406  2.694024599  2.681623186  2.664333399  2.644105557  2.620205338
2.593164066  2.563504103  2.531861198  2.499173273  2.466224797  2.434067095
2.40344978  2.37520292  2.34974024  2.327183566  2.307428591  2.289864039
2.273721191  2.257893312  2.241307516  2.222850455  2.201573059  2.176933584
2.148572675  2.116705094  2.081662915  2.044289931  2.005381778  1.965738305
1.926270922  1.887377529  1.849462655  1.812336763  1.775814043  1.739292744
1.702062504  1.663624149  1.623298794  1.580888937  1.536115261  1.489257282
1.440540739  1.390308435  1.339236569  1.287590993  1.235923991  1.18426495
1.132888416  1.081663941  1.030399604  0.979194032  0.927827684  0.876578694
0.825473601  0.775040847  0.725593637  0.677455428  0.631141613  0.586662129
0.544163797  0.503249145  0.46364594  0.424736961  0.385904641  0.346871984
0.30732042  0.267581456  0.228106687  0.190061803  0.154745451  0.12371338
0.098761478  0.081355326  0.072799762  0.073825843  0.084602467  0.104666562
9.786853017  12.00862423  14.55416098  17.35865233  20.33079203  23.36208517
26.3380851  29.15474048  31.70952266  33.939263  35.80479583  37.29720979
38.43553291  39.26155456  39.83271529  40.21414294  40.47088956  40.66125438
40.83180912  41.01477321  41.2257523  41.46644712  41.72567541  41.98282866
42.21149923  42.38318281  42.47074297  42.45140955  42.30915032  42.03630309
41.63438723  41.11303884  40.49292374  39.79843976  39.05868096  38.30364272
37.56106434  36.85347527  36.19583658  35.59412144  35.04506602  34.5371564
34.05272548  33.56999591  33.06968489  32.53308202  31.94779383  31.30829143
30.61609107  29.87877962  29.1081537  28.31790381  27.52134677  26.72967263
25.95103178  25.18926035  24.4500174  23.73411499  23.04415423  22.38390377
21.75805854  21.1708422  20.62355989  20.1115186  19.62098594  19.12699276
18.59275595  17.97009956  17.20795775  16.25219683  15.14714778  13.80695943
12.22891513  10.42359004  8.422032276  6.287832639  4.086638821  1.911422461
-0.157678276 -2.030240611 -3.641640944 -4.94646531  -5.918227739 -6.56693395
-6.923094526 -7.043266486 -6.997248941 -6.862194052 -6.712161209 -6.61145037
-6.606393531 -6.722613606 -6.964338906 -7.314767984 -7.743362252 -8.211471242
-8.676075453 -9.102500255 -9.462991058 -9.746028464 -9.951743804 -10.09427478
-10.19603742 -10.2828032  -10.37975633 -10.50528497 -10.66919726 -10.86917012
-11.09315805 -11.32086667 -11.52584267 -11.68254127 -11.76757825 -11.76515408
```

```
-11.66781081 -11.47701523 -11.20103013 -10.8545829  -10.45155607 -10.00663882
-9.526624626 -9.015439294 -8.467975166 -7.873953314 -7.22433131  -6.506738682
-5.718856812 -4.860489267 -3.946890611 -2.99757538  -2.03872427  -1.105024663
-0.222202657 0.584690162  1.309369101  1.956037774  2.550968467  3.137344438
3.769142219  4.513640779  5.434270807  6.594472277  8.035754264  9.785535114
];
%此时示工图是按照逆时针走的
data=data';
x=data(:,1);      %第一列泵位移
y=data(:,2);      %第二列泵载荷
n=length(x);%点的个数
jiaodu=linspace(0,0,n-2);
s=linspace(0,0,n-2);
o=linspace(0,0,n-2);
p=linspace(0,0,n-2);
q=linspace(0,0,n-2);
k=linspace(0,0,n-2);
mk=linspace(0,0,n-1);
DK=linspace(0,0,n-1);
fori=3:(n-2)

jiaodu(i)=atan(((y(i)-y(i+2))*(x(i)-x(i-2))-(y(i)-y(i-2)*(x(i)-x(i+2))))/(1+(x(i)-x(i-2))*(x(i)-x(i+2)))
);
 s(i)=sqrt((x(i-2)-x(i-1))*(x(i-2)-x(i-1))+(y(i-2)-y(i-1))*(y(i-2)-y(i-1)));          %pi-2 与
pi-1 之间距离
  o(i)=sqrt((x(i-1)-x(i))*(x(i-1)-x(i))+(y(i-1)-y(i))*(y(i-1)-y(i)));          %pi-1 与 pi 之间
距离
  p(i)=sqrt((x(i)-x(i+1))*(x(i)-x(i+1))+(y(i)-y(i+1))*(y(i)-y(i+1)));          %pi 与 pi+1 之
间距离
  q(i)=sqrt((x(i+1)-x(i+2))*(x(i+1)-x(i+2))+(y(i+1)-y(i+2))*(y(i+1)-y(i+2)));  %pi+1 与 pi+2
之间距离
k(i)=jiaodu(i)/(s(i)+o(i)+p(i)+q(i)) ;          %曲率
end
fori=4:(n-2)
mk(i)=abs(k(i)-k(i+1));          %pi 的曲率变化量
    DK(i)=(mk(i-2)+mk(i-1)+mk(i)+mk(i+1)+mk(i+2))/5
end
```

(2)附录 3.2

Matlab 画图算法：

```
clc; clear all; close all;
axis([0 3 0 70]);
```

```
X=[2.518 2.512 2.504 2.495 2.484 2.472 2.459 2.444 2.427
2.41 2.391 2.372 2.351 2.329 2.305 2.281 2.256 2.229 2.201
2.172 2.142 2.111 2.079 2.046 2.011 1.975 1.938 1.9 1.86 1.82
1.778 1.735 1.69 1.645 1.598 1.55 1.501 1.451 1.399 1.347
1.294 1.239 1.184 1.129 1.072 1.015 0.958 0.901 0.844 0.786
0.729 0.673 0.618 0.563 0.51 0.459 0.409 0.361 0.315 0.272
0.231 0.193 0.158 0.127 0.098 0.074 0.052 0.034 0.02 0.01
0.003 0 0 0.004 0.012 0.023 0.037 0.054 0.074 0.097 0.123
0.152 0.183 0.216 0.251 0.289 0.328 0.369 0.412 0.456 0.501
0.548 0.596 0.645 0.694 0.745 0.797 0.849 0.901 0.954 1.008
1.062 1.116 1.17 1.225 1.279 1.334 1.388 1.442 1.496 1.55
1.603 1.655 1.707 1.758 1.808 1.858 1.906 1.953 1.999 2.043
2.086 2.127 2.167 2.205 2.241 2.275 2.307 2.337 2.365 2.391
2.414 2.435 2.454 2.471 2.485 2.497 2.507 2.515 2.52 2.524
2.525 2.524 2.522
];
U=[39.7 39.665 39.665 38.131 31.822 30.184 28.372 27.047 26.385 23.806
19.17 16.765 14.988 13.245 11.885 14.221 17.114 19.693 20.808 22.446
23.422 21.087 18.996 16.451 15.545 13.698 13.001 14.465 16.277 18.159
17.183 17.323 17.288 16.521 15.371 14.709 15.057 14.43 14.256 14.36
14.534 14.709 14.883 14.778 14.813 14.709 14.953 15.266 15.406 15.301
15.51 16.242 16.73 17.253 17.671 18.612 19.031 19.344 20.146 20.808
21.784 21.959 22.69 23.213 23.492 23.353 23.388 23.806 24.12 24.538
24.886 25.339 28.546 31.16 33.251 35.412 37.957 40.78 46.148 50.4
53.99 55.942 56.883 57.092 57.545 58.103 58.138 58.242 58.347 58.068
58.068 58.242 58.661 58.905 59.462 60.02 60.891 61.205 61.344 60.891
61.275 61.066 60.752 59.811 59.497 58.87 58.033 57.615 57.232 56.465
55.524 55.036 54.408 53.955 53.502 53.537 53.049 53.223 52.7 52.247
52.178 52.247 51.481 50.783 50.33 49.807 49.041 48.274 47.298 46.74
45.834 45.59 45.207 44.963 44.684 44.405 44.196 43.917 43.603 43.115
42.732 41.965 40.85 40.257
];
plot(X,U)
hold on
A1 = [0,25.54];
A2 = [0.152,55.942];
A3 = [2.542,42.732];
A4 = [2.305,11.885];
h1 = plot([A1(1) A2(1)], [A1(2) A2(2)], 'r-o', 'MarkerFaceColor', 'g', 'LineWidth', 2);
h2 = plot([A2(1) A3(1)], [A2(2) A3(2)], 'r-o', 'MarkerFaceColor', 'g', 'LineWidth', 2);
h3 = plot([A3(1) A4(1)], [A3(2) A4(2)], 'r-o', 'MarkerFaceColor', 'g', 'LineWidth', 2);
h4 = plot([A4(1) A1(1)], [A4(2) A1(2)], 'r-o', 'MarkerFaceColor', 'g', 'LineWidth', 2);
```

(3) 附录 3.3

求理论示功图面积程序：

```
function [] = my_area()
clear;
clc;
A = [0,25.546]
B = [0.152,55.9425]
C = [2.524,42.732]
D = [2.305,11.885]
s1 = helen(A,B,C);
s2 = helen(A,C,D);
s = s1+s2;
fprintf('the area is %f\n',s);
functionlen = lenth(x,y)
len = sqrt((x(1)-y(1))^2+(x(2)-y(2))^2);
function s = helen(x,y,z)
a = lenth(x,y);
b = lenth(x,z);
c = lenth(y,z);
p = (a+b+c)/2;
s = sqrt(p*(p-a)*(p-b)*(p-c));
```

(4) 附录 3.4

求泵功图面积程序

```
clear;
%假设 data 是 n 行*2 列的矩阵,n 等于点的个数,
%第一列表示横坐标 xi,第二列表示纵坐标 yi
%点的次序按照逆时针排列
sum=0;
data=[0.0727997620.073825843  0.084602467  0.104666562  0.104683433  0.13534769
0.173583366  0.217076824  0.263398014  0.310294211  0.35594491  0.39921363
0.43943019  0.47681891  0.512070368  0.546232171  0.580490768  0.615960864
0.653516524  0.693687768  0.73663239  0.782178063  0.829917079  0.879415396
0.929984044  0.981292296  1.033074144  1.085214932  1.137710316  1.190598095
1.243883795  1.297481247  1.351184806  1.40468154  1.45760149  1.509684324
1.560502052  1.61007607  1.658549256  1.706270087  1.753736391  1.801498405
1.850038527  1.899651321  1.950348747  2.001811842  2.053401777  2.104319627
2.15337494  2.199675183  2.24242376  2.281141514  2.315748986  2.346583558
2.374347528  2.399995637  2.424581327  2.449088154  2.474274823  2.50060609
2.52800683  2.556141163  2.58429294  2.611516202  2.636763052  2.65901048
2.677365421  2.691133853  2.699848673  2.703260285  2.701301406  2.694024599
2.681623186  2.664333399  2.644105557  2.620205338  2.593164066  2.563504103
2.531861198  2.499173273  2.466224797  2.434067095  2.40344978  2.37520292
2.34974024  2.327183566  2.307428591  2.289864039  2.273721191  2.257893312
2.241307516  2.222850455  2.201573059  2.176933584  2.148572675  2.116705094
```

2.081662915 2.044289931 2.005381778 1.965738305 1.926270922 1.887377529
1.849462655 1.812336763 1.775814043 1.739292744 1.702062504 1.663624149
1.623298794 1.580888937 1.536115261 1.489257282 1.440540739 1.390308435
1.339236569 1.287590993 1.235923991 1.18426495 1.132888416 1.081663941
1.030399604 0.979194032 0.927827684 0.876578694 0.825473601 0.775040847
0.725593637 0.677455428 0.631141613 0.586662129 0.544163797 0.503249145
0.46364594 0.424736961 0.385904641 0.346871984 0.30732042 0.267581456
0.228106687 0.190061803 0.154745451 0.12371338 0.098761478 0.081355326
5.434270807 6.594472277 8.035754264 9.785535114 9.786853017 12.00862423
14.55416098 17.35865233 20.33079203 23.36208517 26.3380851 29.15474048
31.70952266 33.939263 35.80479583 37.29720979 38.43553291 39.26155456
39.83271529 40.21414294 40.47088956 40.66125438 40.83180912 41.01477321
41.2257523 41.46644712 41.72567541 41.98282866 42.21149923 42.38318281
42.47074297 42.45140955 42.30915032 42.03630309 41.63438723 41.11303884
40.49292374 39.79843976 39.05868096 38.30364272 37.56106434 36.85347527
36.19583658 35.59412144 35.04506602 34.5371564 34.05272548 33.56999591
33.06968489 32.53308202 31.94779383 31.30829143 30.61609107 29.87877962
29.1081537 28.31790381 27.52134677 26.72967263 25.95103178 25.18926035
24.4500174 23.73411499 23.04415423 22.38390377 21.75805854 21.1708422
20.62355989 20.1115186 19.62098594 19.12699276 18.59275595 17.97009956
17.20795775 16.25219683 15.14714778 13.80695943 12.22891513 10.42359004
8.422032276 6.287832639 4.086638821 1.911422461 -0.157678276 -2.030240611
-3.641640944 -4.94646531 -5.918227739 -6.56693395 -6.923094526 -7.043266486
-6.997248941 -6.862194052 -6.712161209 -6.61145037 -6.606393531 -6.722613606
-6.964338906 -7.314767984 -7.743362252 -8.211471242 -8.676075453 -9.102500255
-9.462991058 -9.746028464 -9.951743804 -10.09427478 -10.19603742 -10.2828032
-10.37975633 -10.50528497 -10.66919726 -10.86917012 -11.09315805 -11.32086667
-11.52584267 -11.68254127 -11.76757825 -11.76515408 -11.66781081 -11.47701523
-11.20103013 -10.8545829 -10.45155607 -10.00663882 -9.526624626 -9.015439294
-8.467975166 -7.873953314 -7.22433131 -6.506738682 -5.718856812 -4.860489267
-3.946890611 -2.99757538 -2.03872427 -1.105024663 -0.222202657 0.584690162
1.309369101 1.956037774 2.550968467 3.137344438 3.769142219 4.513640779
];

```
%此时示工图是按照逆时针走的
data=data';
x=data(:,1);       %第一列泵位移
y=data(:,2);       %第二列泵载荷
n=length(x);%点的个数
%下面为计算矢量(xi,yi)与矢量(xi+1,yi+1)、原点之间围成的有向面积
A=linspace(0,0,n-1);
fori=1:(n-1)
        %为计算矢量积的第三个分量,除以 2 得到有向三角形面积
       A(i)=(x(i)*y(i+1)-x(i+1)*y(i))/2;            %有向三角形面积
end
```

```
fori=1:(n-1)
sum=A(i)+sum       %不规则图形的有向面积
end
```

问题 4

（1）附录 4.1

用最小二乘法求解方程数多于未知变量的线性方程组的最适解的 c 语言程序：

c 语言实现（引自 http://blog.csdn.net/zhujiang1001/article/details/4043304，经测试，可行）（用最小二乘法求解方程数多于未知变量的线性方程组的最适解(即矛盾方程组)）。

```
#include "stdio.h"
#include "math.h"
int ArgMin(double *mtrx_tmp,int COLUMN,int rowNum,int colNum,double *solution)
{
int k,l,j;
double *eqt;
int *q;
   q=&colNum;
eqt=(double *)malloc(colNum*colNum*sizeof(double));
   //printf("%d",*q);
for(k=0;k<*q-1;k++)
for(l=0;l<*q-1;l++)
      {
eqt[k*COLUMN+l]=0;
for(j=0;j<rowNum;j++)
eqt[k*COLUMN+l]+=*(mtrx_tmp+COLUMN*j+k)*(*(mtrx_tmp+COLUMN*j+l));
      }
for(k=0;k<*q-1;k++)
   {
eqt[k*COLUMN+*q-1]=0;
for(j=0;j<rowNum;j++)
eqt[k*COLUMN+*q-1]+=*(mtrx_tmp+COLUMN*j+*q-1)*(*(mtrx_tmp+COLUMN*j+k));
   }
      /* show the contents of eqts */
      /*int m,n;
printf("eqt:\n");
for(m=0;m<*q-1;m++)
      {
for(n=0;n<*q;n++)
printf("%.2lf\t",eqt[m*COLUMN+n]);
printf("\n");
      }*/
```

```
if(!SolveLinearEqts(eqt,COLUMN,(*q-1),*q,solution)) {
return 0;
   }
return 1;
}
```

测试程序：

```
int ArgMin(double *inMtrx,int COLUMN,int rowNum,int colNum,double *solution);
```

函数功能：用最小二乘法求解方程数多于未知变量的线性方程组的最适解。

测试代码：

```
#define Q 5
#define ROWNUM 6
int main()
    {
double solution[Q-1],eqt[Q][Q]={0};
double
a[ROWNUM][Q]={{3,-2,4,6,-11},{4,3,2,9,-2},{2,6,8,3,4},{2,4,5,3,3},
                                        {0,0,8,6,-20},{3,4,5,6,0}};
ArgMin(&a[0][0],Q,ROWNUM,Q,&solution[0]);
for(i=0;i<Q-1;i++) printf("%.14lf\n",solution[i]);
return 0;
}
```

测试结果：

```
eqts:
42.000000000 38.000000000      61.000000000      84.000000000      -27.000000000
38.000000000      81.000000000      86.000000000      69.000000000      52.000000000
      61.000000000              86.000000000              198.000000000          159.000000000
-161.000000000
      84.000000000              69.000000000              159.000000000          207.000000000
-183.000000000
3.00000000000000
2.00000000000000
-1.00000000000000
-2.00000000000000
```

说明：a, 待求解的方程组数据：

```
                    {3,-2,4,6,-11},
                    {4,3,2,9,-2},
                    {2,6,8,3,4},
                    {2,4,5,3,3},
                    {0,0,8,6,-20},
                    {3,4,5,6,0}
```

以上数据中共有四个变量，六个方程；

b, 测试显示的数据中，“eqts”为通过最小二乘法得出的待求解的线性方程组增广矩阵；下面四行为计算求得的解，与实际完全符合。