

ERRATA

May 2006

Hydraulic Power System Analysis Akers, Gassman, and Smith

From Chapter Synopsis

The first sentence should read:

Chapter 2 outlines details of the U.S. Customary and the S.I. System of units (more modern).

Chapter 2 outlines details of the U.S. Customary and (the more modern) S.I. Systems of units. Conversion between these two systems ...

From Page 37.

The section of the fitting at which the velocity or area is measured may not be the entry to the fitting. The correct section to use should be determined from reference to standard fluid mechanics textbooks.

Pressure losses due to geometric factors in flow passages (e.g. fittings) may be determined with the equation:

$$\Delta p = K_h \frac{\rho v^2}{2} = K_h \frac{\rho Q^2}{2A^2} \quad (3.14)$$

The characteristic, K_h , is a geometry factor and is dependent on the flow passage shape.

From Pages 152 and 153.

There are errors relating to Equation 7.4 and the initial values for x_v and p_L . The corrected text appears below.

The expressions for K_q and K_c , developed in Chapter 7, Section 7.2.3, are repeated here:

$$K_q = C_d w \sqrt{(p_s - p_L)/\rho} \quad (7.5)$$

and:

$$K_c = C_d w \frac{x_v}{2(p_s - p_L)} \sqrt{(p_s - p_L)/\rho} = \frac{x_v}{2(p_s - p_L)} K_q \quad (7.5)$$

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The values that the designer can choose for x_v and p_L to calculate K_q and K_c are really unknown until the system design has been completed and simulated. Obviously not a helpful situation! Thus it will generally be desirable to estimate the coefficients and perhaps change them if the simulation gives results that are very different from the initial estimates. The initial values chosen were $x_v = 0.5 x_{vmax}$, where $x_{vmax} = 0.25E-3$ m and $p_L = 0.25 p_s$, where $p_s = 5.0E+6$ Pa. Using these values, the two valve coefficients have initial estimates:

$$K_q = 0.821 \text{ m}^2/\text{s} \text{ and } K_c = 6.84E-12 \text{ m}^3/\text{s} \cdot \text{Pa}$$

Problem 3.2

Tube wall thickness, ℓ_t 0.1 mm should have a value of 1.0 mm.

Characteristics of a pump and motor transmission system

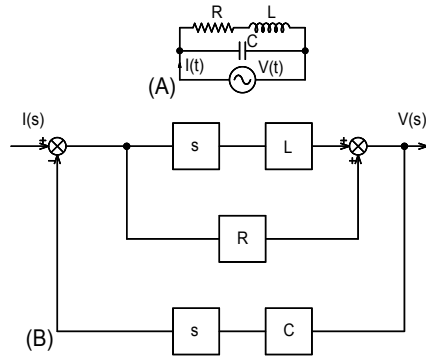
Characteristic	Size	Units
Tube length, ℓ_L	1.2	m
Tube external diameter, d_o	12.0	mm
Tube wall thickness, ℓ_t	0.1	mm
Tube tensile strength, S_t	395	MPa
Oil viscosity, μ	11.5	mPa · s
Oil density, ρ	837	kg/m ³
Pump displacement, D_p	20.0	mL/rev
Pump inlet pressure, p_0	0.0	kPa
Pump volumetric efficiency, η_{vp}	95.0	%
Valve loss factor, K	10.0	
Motor displacement, D_m	37.0	mL/rev
Motor mechanical efficiency, η_{mm}	94.0	%
Motor outlet pressure, p_3	500	kPa

Problem 6.2

There are two errors in the statement of this problem. First the electric circuit shown is a *parallel* circuit and second the quantities $1/s$ and $1/L$ should appear as s and L in the figure. A corrected figure appears below.

The diagram shown in panel (A) of the figure is that of a ~~series~~ *parallel* resonant circuit and panel (B) shows the block diagram equivalent.

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The remainder of the problem statement is correct.

Problem 13.8

Pump flow rate $0 < t < 2.1$, Q 0.496 t L/s should have a value of 0.476 t L/s.

Characteristics of a manufacturing machine system

Characteristic	Size	Units
Cylinder piston area, A_p	1800	mm ²
Cylinder rod side area, A_r	1290	mm ²
Cylinder load force, F	4500	N
Motor displacement, D_m	72.0	mL/rev
Motor discharge pressure, p_r	695	kPa
Motor output torque, T	$10.0 t^{1.4}$	N · m
Pump flow rate $0 < t < 2.1$, Q	0.496 t	L/s
Pump flow rate $2.1 < t$, Q	1.0	L/s

Problems 14.1 and 14.2

Please see the comments on Problem 6.2.

Problem 14.3

There is one error in the statement of this problem.

An additional ~~inductive~~ capacitive element can be added ahead of the inductive/resistive element.

The remainder of the problem statement is correct, but may not give sufficient guidance to the student. It is suggested that the following sequence be followed when approaching this problem:

1. Ensure that a load resistance is present between the output of the series inductive element and ground. Call this load resistance R_L .
2. Reduce the full block diagram with all resistance, capacitance, and inductance values included. Specify the transfer function between an applied flow rate and the pressure that will appear across the load resistance.
3. Simplify the block diagram by eliminating the parasitic resistance and capacitance elements associated with the series inductive element. Find the simplified transfer function between the applied flow rate and the pressure across the load resistance.
4. Use the inductance, $L = 876\text{E}+3 \text{ Pa} \cdot \text{s}^2/\text{m}^3$, used in Chapter 14. Examine the denominator transfer function and select a suitable value of C_2 , the shunt capacitance. The designed resonant frequency should be one tenth of the fundamental pump frequency. The value of load resistance, R_L , should be chosen after reviewing the material on spring-mass-damper systems in Chapter 6.
5. Examine the physical size of the capacitor if it is a cylinder of length equal to the diameter.
6. Use a suitable program to develop the frequency response curves for the simplified filter.
7. Return to the system that includes the parasitic resistance and capacitance values in the series inductance element. Examine the frequency response curves. WARNING. If you use the Visual Basic program on the attached CD, the very low damping of the numerator term may not yield the correct phase angle curve. Try increasing the value of R until the numerator

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damping factor is about 0.2. The program should now behave. In order to present the phase angle curve for the low damping situation, you may need to alter the code temporarily.

8. Observe that the parasitic resistance and capacitance curves have introduced a deep notch into the response. Try altering ALL resistance, capacitance, and inductance values. The goal is to retain the denominator resonant frequency at one tenth the pump frequency and move the notch frequency to the pump fundamental frequency. Do not worry about selecting pipe sizes, just assume that you have total control. In practice, note that this will not be true.
9. Finally try the effect of lowering the load resistance until the damping in the denominator causes a resonance effect. Examine the next suggestion only in a quantitative manner. Consider the expected difference between a load consisting of a valve vs. a load formed by a motor.

Programming problem with Program chap6\frq_rsp.xls

Since the Excel Visual Basic program to draw frequency response plots was written, it has been found that transitions when the arc-tangent value changes from near -180 to near +180 were not well handled. An attempt has been made to remedy this. The new main program Sub freqresp() incorporates these changes. The Function phscmplx(a As complex) As Double must also be replaced. Note the comment included in Sub freqresp():

```
' *****  
' WARNING. This segment of code works for smooth functions. It is  
' not sufficiently sophisticated to detect the difference between a  
' numerator and a denominator function when damping is very low and  
' phase angle changes suddenly by nearly +-180 deg.  
' *****
```

Also note that there were occasions when single precision arithmetic was not adequate. The main program, Sub freqresp(), has been

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changed to double precision. The reader should change the other subroutines where appropriate.

Note that it is possible to copy the modified code from Adobe Reader using the Select button on the menu bar.

```
'...v....1....v....2....v....3....v....4....v....5....v....6....v....7.^
',
Sub freqresp()
',
' R. J. Smith
' Revised by insertion of a plotting sub routine February 2006
' Revised by altering the angle determining function phscmplx() and the
' manner in which sudden jumps of nearly 360 deg are handled.
' April 2006.
',
' Programme description
' -----
' This programme takes a ratio of two polynomials (Laplace domain)
' and generates plots of amplitude ratio in decibels vs. log frequency
' and phase angle in degrees vs. log frequency.
' Note that a user defined function complex has been specified to make
' it easier to perform the complex arithmetic calculations that are
' necessary.
' NOTE. The programme will only perform as expected if the minimum
' frequency is chosen to be low enough that the phase angle is
'  $-\pi < \phi < \pi$ .
',
' Glossary of variables
' -----
' Integer
' i          General loop counter.
' icol       Current value of column address.
' icol0      Origin cell in top left-hand corner of worksheet.
' irow       Current value of row address.
' irow0      Origin cell in top left-hand corner of worksheet.
' nd         Number of coefficients in the denominator polynomial.
' nfreq      Number of frequencies, i.e., just 2 for maximum and
'            minimum.
' nint       Number of plotting intervals.
' nn        Number of coefficients in the numerator polynomial.
',
' Double precision
' amp        Amplitude of the frequency response, ultimately in
'            decibels.
```

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```

' cffd()      Array of denominator coefficients including the
'             constant.
' cffn()      Array of numerator coefficients including the
'             constant.
' delomega    Multiplying factor used to generate a frequency series
'             that is evenly spaced on a logarithmic axis.
' deltaphi    Increment added to the phase angle (phiold) as the
'             frequency is advanced.
' omegai      The complex part of the frequency, i.e. jomega., but
'             expressed as a real quantity. That is a complex number
'             is a + jb, but b is real.
' omegammx() Array containing the minimum and maximum frequencies
'             selected by the user for generating the Bode plots.
' phi         The phase angle of the frequency response.
' phitemp     The phase angle determined from phscmplx. This angle is
'             in the range  $-2\pi < \text{phitemp} < 2\pi$ .
' phitempold  The phase angle determined from phscmplx in the previous
'             step.
' phiold      The phase angle for the function determined from the
'             previous step.
'
' String
' crlf        <RETURN><LINE FEED> used in message and input boxes
'             to break lines.
' Complex
' a           Numerator polynomial value evaluated at jomega.
' b           Denominator polynomial value evaluated at jomega.
' c            $c = a/b$ 
' omega       Frequency expressed as  $\omega = 0 + j\omega_i$ 
'
Dim i As Integer, icol As Integer, icol0 As Integer, _
    iphi As Integer, _
    irow As Integer, irow0 As Integer, nd As Integer, _
    nfreq As Integer, nint As Integer, nn As Integer
Dim amp As Double, cffd(10) As Double, cffn(10) As Double, _
    delomega As Double, deltaphi As Double, _
    omegai As Double, omegammx(2) As Double, _
    phi As Double, phitemp As Double, phiold As Double, _
    phitempold As Double
Dim crlf As String
Dim a As complex, b As complex, c As complex, omega As complex, _
    temp As complex
'
' Variables for bdplot
' Integer
' icolx       Column position of the output times. Used in the

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'          plotting subroutine.
' icoly(2)  Column position of outputs generated by the programme.
'          The array is used to allow multiple sets of dependent
'          data to be plotted on the same chart.
' ncol     Number of sets of dependent variables to be plotted
'          on the same chart.
' nend     Spreadsheet row number for the last row of output data.
' nstrt    Spreadsheet row number for the first row of output data.
'
' String
' pltlabl  Name to be given to the chart generated by subroutine
'          bdplot.
' shtlabl  Name of the worksheet from which columns are read before
'          plotting by subroutine bdplot.
' xlabel   Label for the independent variable axis plotted by
'          subroutine bdplot.
' ylabel   Label for the dependent variable axis plotted by
'          subroutine bdplot.
'
Dim icolx As Integer, icoly(5) As Integer, ncol As Integer, _
    nend As Integer, nstrt As Integer
Dim pltlabl As String, shtlabl As String, xlabel As String, _
    ylabel As String
'
icol0 = 1
irow0 = 1
'
crlf = Chr(13) & Chr(10)
pi = 4# * Atn(1#)
'
' Warning to user about accidentally deleting input data on the
' worksheet.
'
MsgBox prompt:="*****" _
    & crlf & _
    "    NOTE! frq_rsp does NOT contain code to write" _
    & crlf & _
    "    a sample transfer function to the worksheet." _
    & crlf & _
    "    DO NOT ACCIDENTALLY ERASE COLUMNS 1 TO 6." _
    & crlf & _
    "See the Visual Basic code for retrieving the _
    missing data." & crlf & _
    "*****", _
Title:="MESSAGE TO USER"
'

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```
' For user assistance, the contents of the first 6 columns are:
' Column 1
' nn 5   nd 6   nfreq 2
' cffn(1) 10  cffd(1) 1  omegamin  0.1
' cffn(2) 83  cffd(2) 11  omegamax  100
' cffn(3) 0   cffd(3) 45
' cffn(4) 324 cffd(4) 85
' cffn(5) 168 cffd(5) 72
'           cffd(6) 24
'
' Write header information for the frequency, amplitude, and phase
' angle columns.
'
irow = irow0
icol = icol0 + 6
Call header(irow, icol)
'
' Read in the number of numerator coefficients and the values of the
' coefficients from the spreadsheet.
'
irow = irow0
icol = icol0 + 1
Call inpt(nn, cffn(), irow, icol)
'
' Read in the number of denominator coefficients and the values of the
' coefficients from the spreadsheet.
'
irow = irow0
icol = icol0 + 3
Call inpt(nd, cffd(), irow, icol)
'
' Read in the lower and upper frequencies required for the Bode plots.
'
irow = irow0
icol = icol0 + 5
Call inpt(nfreq, omegammx(), irow, icol)
'
' Frequency response charts are plotted with logarithmic frequency
' axes. Thus the frequency increment should be a multiplier so
' the plotted increment will be a fixed increment.
'
nint = 250
delomega = (Log(omegammx(2)) - Log(omegammx(1))) / nint
'
' Excel only provides a function for natural logarithms.
' Conversion to log base 10 to avoid need to use e when
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```

' inverting the logarithm.
,
delomega = delomega / Log(10#)
delomega = 10# ^ delomega
,
omegai = omegammx(1)
phiold = 0#
phitempold = 0#
,
' Specify the first cell in which output results will be written.
,
irow = irow0 + 2
icol = icol0 + 6
,
' Try to avoid roundoff error. If the last frequency exceeds omegamax
' by even a very small quantity, the Excel will increase the logarithmic
' scaling on the chart by one decade. This is undesirable, thus the
' output is curtailed after (nint-1).
,
For i = 0 To (nint - 1)
,
omega.real = 0#
omega.imag = omegai
,
' Evaluate the numerator and denominator coefficients when s is
' replaced by jomega.
,
a = plyevlcmplx(nn, cffn(), omega)
b = plyevlcmplx(nd, cffd(), omega)
,
' Find the result of dividing the denominator into the numerator as
' complex numbers.
,
c = cmplxdiv(a, b)
,
' Find the amplitude of the quotient and convert to decibels.
,
amp = ampcmplx(c)
amp = 20# * Log(amp) / Log(10#)
,
' Find the phase angle of the quotient.
,
phitemp = phscmplx(c) * 180# / pi
,
' *****
' WARNING. This segment of code works for smooth functions. It is

```

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```

' not sufficiently sophisticated to detect the difference between a
' numerator and a denominator function when damping is very low and
' phase angle changes suddenly by nearly +-180 deg.
' *****
' Avoid sudden and incorrect shift by 360 deg when the atn() function
' switches from near -180 deg to near +180 deg or the reverse.
' The strategy is to compare the current evaluation of the angle
' atn(a/b) with the immediately previous value. If a shift of nearly
' 360 deg is detected, the increment of phase angle that must be added
' to the previous evaluation (phiold) is adjusted by +-360.
,
' Determine if the phase angle plot is being drawn above or
' below the frequency axis.
,
iphi = Sgn(phiold)
,
' Determine if a nearly 360 deg jump has occurred since the previous
' step. Determine the appropriate increment for the phase
' angle.
,
If (Abs(phitempold - phitemp) > (0.99 * 180#)) Then
,
deltaphi = phitemp - phitempold + iphi * 360#
,
Else
,
deltaphi = phitemp - phitempold
,
End If
,
' Increment the phase angle appropriately and save the current values
' of phase angle and atn(a/b) for use in the next iteration.
,
phi = phiold + deltaphi
phiold = phi
phitempold = phitemp
,
ActiveSheet.Cells(irow, icol).Value = omegai
ActiveSheet.Cells(irow, (icol + 1)).Value = amp
ActiveSheet.Cells(irow, (icol + 2)).Value = phi
,
omegai = omegai * delomega
irow = irow + 1
,
Next i
,

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```

'*****
' The data has been written to the worksheet. The next calls plot
' selected columns from the worksheet.
' NOTE. Once an Excel chart has been generated for a given set of data
' on the spreadsheet, any changes in this data are automatically
' reflected in the chart. Subroutine bdplot recognizes this and only
' generates a new chart when an old chart of the same name does not
' exist.
'*****
,
' When the chart generation procedure requires columns, that is "ranges"
' of data, the subroutine must know which worksheet should be addressed.
' The next command writes the current worksheet name into the string
' variable shtlabl so this information can be passed to the plotting
' subroutine bdplot.
,
shtlabl = ActiveSheet.Name
nstrt = irow0 + 2
nend = nstrt + nint
icolx = icol0 + 6
,
' Plot the amplitude results.
,
icoly(1) = icol0 + 7
ncol = 1
xlabl = "FREQUENCY rad/s"
ylabl = "AMPLITUDE dB"
pltlabl = "AMPLITUDE"
Call bdplot(icolx, icoly(), ncol, nend, nstrt, shtlabl, _
xlabl, ylabl, pltlabl)
,
' Plot the phase angle results.
,
icoly(1) = icol0 + 8
ncol = 1
xlabl = "FREQUENCY rad/s"
ylabl = "PHASE ANGLE degrees"
pltlabl = "PHASE"
Call bdplot(icolx, icoly(), ncol, nend, nstrt, shtlabl, _
xlabl, ylabl, pltlabl)
,
MsgBox prompt:="*****" & crlf & _
"Now that the program has been run with" & crlf & _
"some sample data, the user may change" & crlf & _
"values in columns 1 to 6 as they see fit." & crlf & _
"*****", _

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        Title:="MESSAGE TO USER"
    ,
End Sub
    ,
'*****
'...v...1...v...2...v...3...v...4...v...5...v...6...v...7.^
    ,
Function phscmplx(a As complex) As Double
    ,
' Programme description
' -----
'     This function determines the phase angle of a complex number.
' For controls purposes, phase angles are defined as negative when
' in the 4th quadrant and they become more negative as the vector
' moves 3rd, 2nd, to 1st.
' This subroutine yields a value of  $0 \leq \phi < \pi$  for quadrants 1 and 2.
'  $0 > \phi \geq -\pi$ , that is a negative value is returned, for quadrants
' 3 and 4.
    ,
Dim quad As Integer
Dim phi As Double, x As Double, y As Double
    ,
' Determine the quadrant in which the vector is located by examining
' the relative values of a.real and a.imag.
    ,
If ((a.real >= 0#) And (a.imag >= 0#)) Then
    ,
quad = 1
    ,
ElseIf ((a.real <= 0#) And (a.imag >= 0#)) Then
    ,
quad = 2
    ,
ElseIf ((a.real <= 0#) And (a.imag <= 0#)) Then
    ,
quad = 3
    ,
ElseIf ((a.real >= 0#) And (a.imag <= 0#)) Then
    ,
quad = 4
    ,
End If
    ,
x = Abs(a.real)
y = Abs(a.imag)

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```
,  
' Evaluate the arc tangent by forcing the value to lie in the first  
' quadrant.  
' Allow for an infinity condition by treating x = 0 separately.  
,  
If (x > 0) Then  
,  
phi = Atn(y / x)  
,  
Else  
,  
phi = pi / 2#  
,  
End If  
,  
' Evaluate the phase angle.  
,  
If (quad = 1) Then  
,  
phscmplx = phi  
,  
ElseIf (quad = 2) Then  
,  
phscmplx = pi - phi  
,  
ElseIf (quad = 3) Then  
,  
phscmplx = -pi + phi  
,  
Else  
,  
phscmplx = -phi  
,  
End If  
,  
End Function
```