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:

$$\Delta p = K_h \frac{v^2}{2} = K_h \frac{Q^2}{2A^2}$$

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:

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

and:

$$K_c = C_d w \frac{x_v}{2(p_s - p_L)} \frac{\sqrt{(p_s - p_L)/\rho}}{x_v} = \frac{x_v}{2(p_s - p_L)} K_q$$
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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 \( x_v = 0.5x_{v_{\text{max}}} \), where \( x_{v_{\text{max}}} = 0.25E^{-3} \) m and \( p_L = 0.25p_s \), where \( p_s = 5.0E+6 \) Pa. Using these values, the two valve coefficients have initial estimates:

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

Problem 3.2
Tube wall thickness, \( \ell_t \) 0.1 mm should have a value of 1.0 mm.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Size</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube length, ( \ell_L )</td>
<td>1.2</td>
<td>m</td>
</tr>
<tr>
<td>Tube external diameter, ( d_o )</td>
<td>12.0</td>
<td>mm</td>
</tr>
<tr>
<td>Tube wall thickness, ( \ell_t )</td>
<td>0.1</td>
<td>mm</td>
</tr>
<tr>
<td>Tube tensile strength, ( S_t )</td>
<td>395</td>
<td>MPa</td>
</tr>
<tr>
<td>Oil viscosity, ( \mu )</td>
<td>11.5</td>
<td>mPa \cdot s</td>
</tr>
<tr>
<td>Oil density, ( \rho )</td>
<td>837</td>
<td>kg/m(^3)</td>
</tr>
<tr>
<td>Pump displacement, ( D_p )</td>
<td>20.0</td>
<td>mL/rev</td>
</tr>
<tr>
<td>Pump inlet pressure, ( p_0 )</td>
<td>0.0</td>
<td>kPa</td>
</tr>
<tr>
<td>Pump volumetric efficiency, ( \eta_{vp} )</td>
<td>95.0</td>
<td>%</td>
</tr>
<tr>
<td>Valve loss factor, ( K )</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>Motor displacement, ( D_m )</td>
<td>37.0</td>
<td>mL/rev</td>
</tr>
<tr>
<td>Motor mechanical efficiency, ( \eta_{mm} )</td>
<td>94.0</td>
<td>%</td>
</tr>
<tr>
<td>Motor outlet pressure, ( p_3 )</td>
<td>500</td>
<td>kPa</td>
</tr>
</tbody>
</table>

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.
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/capacitative 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, $L = 876E+3 \text{ Pa} \cdot \text{s}^2/\text{m}^3$, 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
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
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.

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
−π < φ < π.

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.
freq 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.
Array of denominator coefficients including the constant.

Array of numerator coefficients including the constant.

Multiplying factor used to generate a frequency series that is evenly spaced on a logarithmic axis.

Increment added to the phase angle (phiold) as the frequency is advanced.

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.

Array containing the minimum and maximum frequencies selected by the user for generating the Bode plots.

The phase angle of the frequency response.

The phase angle determined from phscmplx. This angle is in the range -2pi < phitemp < 2pi.

The phase angle determined from phscmplx in the previous step.

The phase angle for the function determined from the previous step.

<RETURN><LINE FEED> used in message and input boxes to break lines.

Numerator polynomial value evaluated at jomega.

Denominator polynomial value evaluated at jomega.

\[ c = \frac{a}{b} \]

Frequency expressed as omega = 0 + jomegai

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, omegamnmx(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

Column position of the output times. Used in the
plotting subroutine.

icol(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.
xlabl Label for the independent variable axis plotted by
subroutine bdplot.
ylabl 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, xlabl As String,
ylabl 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  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, omegamx(), 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(omegamx(2)) - Log(omegamx(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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\[ \text{delomega} = \text{delomega} / \log(10) \]
\[ \text{delomega} = 10^\text{delomega} \]
\[ \omega_{i} = \omega_{i \max}(1) \]
\[ \phi_{old} = 0 \]
\[ \phi_{tempold} = 0 \]

Specify the first cell in which output results will be written.

\[ i_{row} = i_{row0} + 2 \]
\[ i_{col} = i_{col0} + 6 \]

Try to avoid roundoff error. If the last frequency exceeds omega_{\max}
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 \((n_{int}-1)\).

For \(i = 0 \text{ To } (n_{int} - 1)\)

\[ \omega_{\text{real}} = 0 \]
\[ \omega_{\text{imag}} = \omega_{i} \]

Evaluate the numerator and denominator coefficients when \(s\) is
replaced by \(j\omega_{i} \).

\[ a = \text{plyevlcmplx}(nn, \text{cffn}(), \omega_{i}) \]
\[ b = \text{plyevlcmplx}(nd, \text{cffd}(), \omega_{i}) \]

Find the result of dividing the denominator into the numerator as
complex numbers.

\[ c = \text{cmplxdiv}(a, b) \]

Find the amplitude of the quotient and convert to decibels.

\[ \text{amp} = \text{ampcmplx}(c) \]
\[ \text{amp} = 20 \times \log(\text{amp}) / \log(10) \]

Find the phase angle of the quotient.

\[ \phi_{temp} = \text{phscmplx}(c) \times 180 / \pi \]

******************************************************************************

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.

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
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 & 
"***************************"
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. $0 \geq \phi \geq -\pi$, 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)
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