

Kinematics – ME 337

Microsoft Excel: Advanced Topics

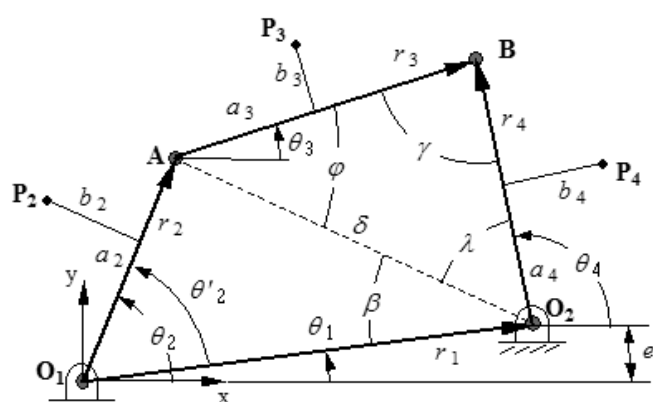
Spreadsheets can be powerful tools for engineers particularly because they can combine data, equations, charts, and graphics. In this course, we will use some of the lesser-known Excel functions and tools, such as complex-numbers, matrix functions, and the Excel solver. The purpose of this handout is to show an example of an engineering design spreadsheet and provide a review of some of the lesser-known Excel functions.

Creating the four-bar spreadsheet for this course requires only a basic understanding of Excel. If you are new to Excel, then you may want to view a basic tutorial or two. You can get to many free tutorials by simply searching online (search for "Excel tutorials", "Excel basics tutorial", etc.) You will want to learn about entering data, creating formulas, referencing cells, using absolute and relative references, and copying formulas.

SPREADSHEET STYLE

The example shown below should give you an idea of what a professional design spreadsheet might look like. As with any program, report, or technical document, it is important to communicate properly. This can be done with graphics, labels, comments, etc. For class assignments, you do not have to create graphics as shown below, but you ought to document your spreadsheet appropriately so that it can be interpreted by others.

	A	B	C	D	E	F	G	H	I	J
1	Title: 4-Bar Spreadsheet						Date: 9/23/2003			
2	Subject: Kinematics (ME 337)						Name: Jon Wittwer © 2003			
3										
4										
5	Linkage Dimensions									
6	r_1	2	cm							
7	r_2	1	cm							
8	r_3	2.5	cm							
9	r_4	2.5	cm							
10										
11	a_3	5	cm							
12	b_3	0	cm							
13										
14	θ_1	5	degrees							
15	e	0.174311	cm							
16										
17										
18										
19										
20	θ_2	θ'_2	δ	β	ψ	λ	θ_3	θ_4	P_{3x}	P_{3y}
21	degrees	degrees	cm	radians	radians	radians	radians	radians	cm	cm
22	0	-5	1.0076	0.0866	1.3679	1.3679	1.5418	1.7744	1.1451	4.9979
23	10	5	1.0076	0.0866	1.3679	1.3679	1.3685	1.7744	1.9892	5.0717
24	20	15	1.0660	0.2453	1.3560	1.3560	1.1980	1.6277	2.7610	4.9985
25	30	25	1.1725	0.3687	1.3341	1.3341	1.0526	1.5260	3.3425	4.8436
26	40	35	1.3128	0.4522	1.3051	1.3051	0.9402	1.4716	3.7141	4.6812
27	50	45	1.4736	0.5005	1.2716	1.2716	0.8584	1.4568	3.9110	4.5501
28	60	55	1.6449	0.5213	1.2356	1.2356	0.8016	1.4720	3.9780	4.4582



MATRIX FUNCTIONS

Excel can be used to solve systems of linear equations. This can be helpful when you are required to do free-body diagrams of mechanisms and solve for the forces at the joints. Excel performs matrix operations when you press **Ctrl+Shift+Enter** after creating your formula.

Example: Multiply a 2x2 matrix by a 2x1 vector.

Step 1: Enter the values of these two matrix on the spreadsheet.

Step 2: Block out a 2x1 space where the product will reside ($2 \times 2 * 2 \times 1 = 2 \times 1$)

Step 3: For the now-highlighted region, enter the following equation:

=MMULT(A2:B3,C2:C3)

Step 4: After typing the equation, press **Ctrl+Shift+Enter**

System of Equations:

Solve $AX = B$ for X using the equation $X = A^{-1}B$

	D3	= {=MMULT(MINVERSE(A3:B4),F3:F4)}				
	A	B	C	D	E	F
1						
2	A			X		B
3	4	5		1.142857		1
4	3	2		-0.71429		2
5						

Note: After pressing Ctrl+Shift+Enter, Excel indicates a matrix operation by surrounding the formula with { } as shown above.

Matrix Command Summary:

MINVERSE(array) – Returns the inverse of a matrix array

MDETERM(array) – Returns the determinant of a matrix array

MMULT(array1,array2) – Returns the product of two matrix arrays

TRANSPOSE(array) – Returns the transpose of an array

SOME USEFUL TRIG FUNCTIONS

DEGREES(angle_in_radians) – Converts to degrees

RADIANS(angle_in_degrees) – Converts to radians

Note: Excel functions work with **radians**, not degrees. **Do not forget to convert degrees to radians before using trig functions!**

PI() – Returns the value of π .

ATAN2(x,y) – Returns an angle between $-\pi$ and $+\pi$.

Hint: If you want to use Greek symbols, change the font to "Symbol".

IF STATEMENTS IN EXCEL FORMULAS

IF(logical_statement, value_if_true, value_if_false) – Behaves like a typical "if" statement, with the logical_statement being a condition such as A2<B4. The ATAN2() function could be written as a nested IF statement as shown below:

$$=IF(x>0,ATAN(y/x),IF(y>0,ATAN(y/x)+PI(),ATAN(y/x)-PI()))$$

Note: An "IF" statement can be useful when creating formulas for θ_3 and θ_4 using the algebraic equations for the 4-bar mechanism.

COMPLEX NUMBERS

Excel has a few functions that work specifically with complex numbers. In order to use these functions, you must install the Analysis ToolPak Add-in. Go to **Tools -> Add-Ins...**, select the **Analysis ToolPak** and press OK.

Excel functions that return complex numbers return them as **text** in *rectangular* form ($a+bi$). You should remember to always use **radians** when working with complex numbers and trig functions.

Example: Converting from *rectangular* to *exponential* form.

$$\mathbf{R} = (a + bi) = re^{i\theta}$$

$$r = \sqrt{a^2 + b^2} \quad =\text{IMABS}("3+4i")$$

$$\theta = \arctan(b/a) \quad =\text{IMARGUMENT}("3+4i") \text{ in radians}$$

Note: IMARGUMENT(COMPLEX(3,4)) is the same as ATAN2(3,4)

Example: Converting from *exponential* to *rectangular* form.

$$a = r \cos \theta \quad b = r \sin \theta$$

$$=\text{COMPLEX}(r\cos\theta, r\sin\theta)$$

	A	B	C
1		Result	Formula
2		3+4i	=COMPLEX(3,4)
3		4	=IMAGINARY("3+4i")
4		3	=IMREAL("3+4i")
5		0.927295	=IMARGUMENT("3+4i")
6		5	=IMABS("3+4i")
7	a	2+3i	"2+3i" entered as text
8	b	4+2i	"4+2i" entered as text
9	a/b	0.7+0.4i	=IMDIV(B7,B8)
10	a*b	2+16i	=IMPRODUCT(B7,B8)
11	a+b	6+5i	=IMSUM(B7,B8)
12	a-b	-2+i	=IMSUB(B7,B8)

THE EXCEL SOLVER

Excel has a powerful optimization algorithm that can be used to solve systems of nonlinear equations. It is an add-in, so if it is not already installed, go to **Tools -> Add-Ins...** , select **Solver** and press OK.

In the following example, the solver is used to find values for θ_2 and θ_3 that satisfy the given equations. The simple way to solve the system is to first make the equations implicit (equal to zero). Then create an objective function that when **minimized**, drives both equations to zero. Minimizing the **sum of the squares** of each equation will accomplish this.

	A	B	C	D	E	F	G
1							
2	Analysis Variables (knowns)			$r_2 \cos \theta_2 + r_3 \cos \theta_3 - r_4 = 0$ $r_2 \sin \theta_2 + r_3 \sin \theta_3 = 0$			
3	r_2	3					
4	r_3	4					
5	r_4	2					
6							
7	Design Variables (unknowns)						
8	θ_2	4.459708	radians				
9	θ_3	7.095941	radians				
10							
11	System of Equations						
12	f_1	-3.2E-06		=B3*COS(B8)+B4*COS(B9)-B5			
13	f_2	1.1E-06		=B3*SIN(B8)+B4*SIN(B9)			
14							
15	Objective Function						
16	obj	1.16E-11		=B12^2+B13^2			

When running the solver, the objective function is the target cell, and the unknowns are the cells that you want to allow the solver to change (see below).

