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Engineering Analysis in the MET Engineering Dynamics Course

Zhongming (Wilson) Liang

Purdue University Fort Wayne

Abstract

This paper discusses the author's experience of expanding engineering analysis in some example and homework problems in the MET engineering dynamics course, using Microsoft Excel as the tool. The expanded analysis allows students to better understand engineering analysis. Their satisfaction for the course was significantly increased.

Introduction

In comparison with some other engineering technology technical courses, engineering dynamics is more abstract and hence more difficult to the students. Also typical students do not find apparent applications of the knowledge in their job, whether they work full-time or as co-ops. Therefore, making the course interesting has been a challenge.

Starting a few years ago, the author has placed computer-aided solid modeling of mechanisms into the course. Solid models play the role of physical models in the past in position analysis and mobility analysis. Students gain knowledge of using CAD for design analysis. The figure below here is an example of CAD solid models required for the students as homework.

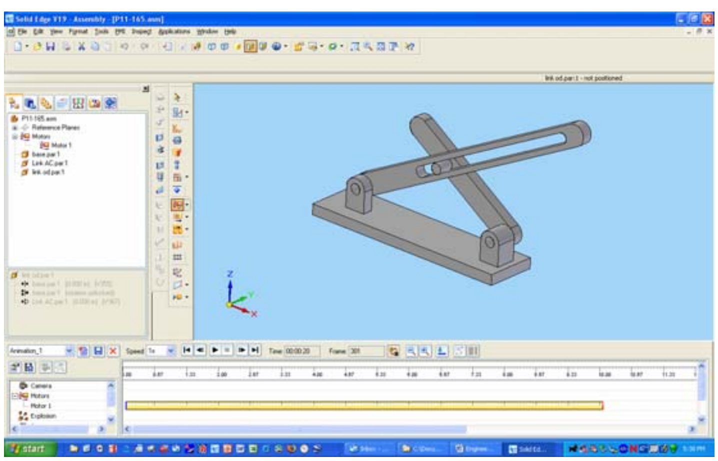

Fig 1. CAD model of a mechanism

CAD solid models are effective and convenient for mobility analysis and position analysis but provide limited help for velocity and acceleration analysis and kinetics. The author realized that he also needed to find new methods to teach engineering analysis in the course.

In the alumni survey of 2005, alumni commented that the engineering dynamics course materials were too similar to those in general physics course, and also suggested to include more instruction in the curriculum of how to use Excel for engineering analysis. These two comments were valid and valuable.

In the dynamics course of spring 2006, the author added expanded analysis to the common algebraic solutions of some problems, with Excel as a tool. The expanded analysis allowed students to better understand the physics and the solutions of the problems. The analysis also increased the students' abilities of using Excel for engineering analysis.

In the following, the author will use several examples to illustrate his approach. The sample problems and problems are from Reference 1.

Using Excel Solver for Dynamics Problems

Many problems in the course require solution of algebraic or trigonometric equations, or maximums or minimums of functions. In addition to analytical solution, Excel Solver is introduced to students. It is more practical and reliable for our MET students to solve real engineering problems in the future. They enjoy learning the method.

Here is an example. The position of a particle which moves along a straight line is defined by the relation $x = t^3 - 6t^2 - 15t + 40$. Determine (a) the time at which the velocity will be zero, (b) the position of the particle at the time.

The common algebraic solution as given in the textbook is to differentiate the x(t) equation into a v(t) equation and then to find the zeros of the v(t) equation.

The expanded analysis is to apply the concept that the velocity is zero when the position is at an extremum and therefore to convert the problem to finding the time when the x(t) function is at maximum or minimum. The optimization problem is solved on Excel as shown below.

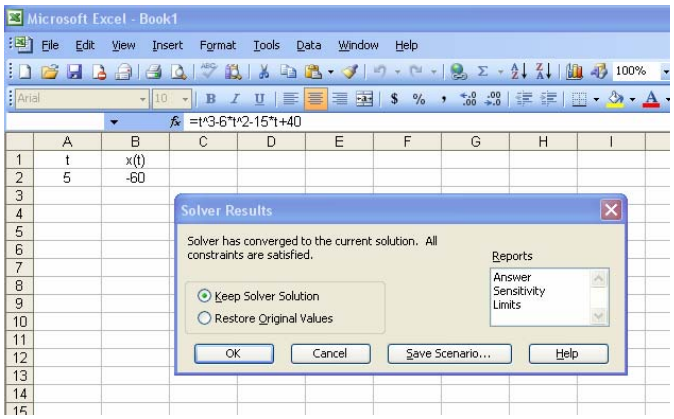

Fig 2. Finding the minimum of a function on Excel

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Further Engineering Analysis of Particle Kinematics Problems

Especially if the problem involves more than one particle, graphs significantly help with illustrating the relation between their motion and hence with students' understanding of the problem.

Here is an example. An open-platform elevator is moving down a mine shaft at a constant velocity v_e = 7.5 m/s when the elevator platform hits and dislodges a stone. Determine when and where the stone will hit the elevator platform.

The common algebraic solution to this problem is to develop an equation that equates the elevator position, a time-function, to the stone position, another time function, and to solve the equation for the time that holds the equation true.

In the further analysis, the author asks the students to plot the elevator position curve and the stone position curve as shown below. The graph illustrates that because the elevator motion driven by a motor is linear and the stone motion driven by the gravity is non-linear the two meet again at a certain time and a certain location down. The students gain better understanding of the problem.

In the current spring of 2007, the author also teaches using finite difference to estimate velocity.

Time (s)	Elevator Pos (m)	Stone Pos (m)
0.00	0.000	0.000
0.05	-0.375	-0.012
0.10	-0.750	-0.049
0.15	-1.125	-0.110
0.20	-1.500	-0.196
0.25	-1.875	-0.306
0.30	-2.250	-0.441
0.35	-2.625	-0.601
0.40	-3.000	-0.784
…………	…………	…………

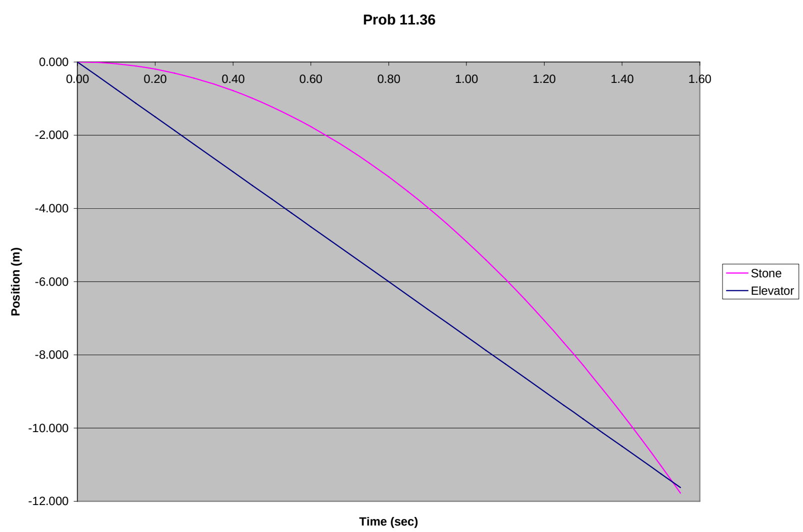

Fig 3. Using Excel graph to illustrate the positional relationship of two particles in motion

Further Study of Radial and Transverse Components in Particle Motion

The method of radial and transverse components is difficult to our MET students because it is entirely new and uses more of calculus. Since this method is valuable in mechanical engineering, the author has decided to teach at least position analysis and velocity analysis with this method.

To help students understand the position analysis, the author assigns a homework problem of making a position plot based on radial and transverse coordinates.

Here is an example as shown in Fig. 4. The rotation of rod OA about O is defined by the relation $\theta = t^3 - 4t$, where θ is in radian and t in seconds. Collar B slides along the rod in such a way that its distance from O is $r = 25t^3 - 50t^2$, where r in millimeters and t in seconds.

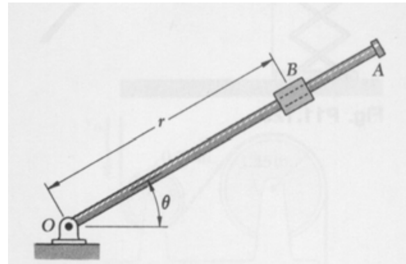

Fig 4. Radial and transverse coordinates

Though radial and transverse coordinates are first converted to x and y coordinates because Excel cannot make polar plots, students gain better understanding of the method from the plot especially with the author's explanation in the class.

The author also gives the class demos of making polar plots on Maple.

t (sec)	r (mm)	θ (rad)	X (mm)	Y (mm)
0	0.00	0.00	0.00	0.00
0.1	-0.48	-0.40	-0.44	0.18
0.2	-1.80	-0.79	-1.26	1.28
0.3	-3.83	-1.17	-1.48	3.53
0.4	-6.40	-1.54	-0.22	6.40
0.5	-9.38	-1.88	2.81	8.94
0.6	-12.60	-2.18	7.25	10.30
0.7	-15.93	-2.46	12.34	10.07
0.8	-19.20	-2.69	17.26	8.41
0.9	-22.28	-2.87	21.46	5.95
1	-25.00	-3.00	24.75	3.53

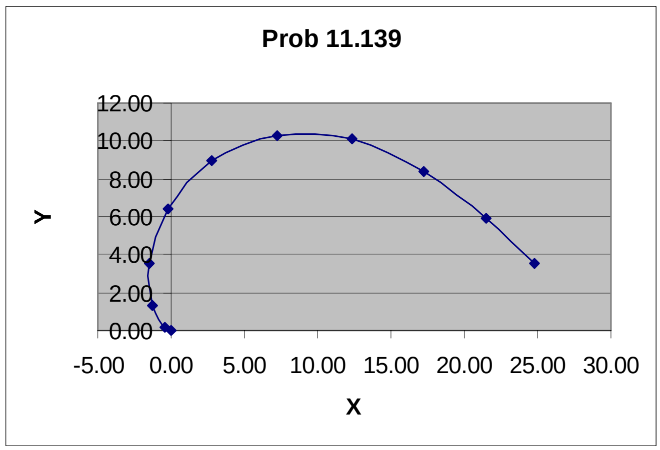

Fig 5. Using an Excel graph to illustrate concepts of radial and transverse coordinates

Further Analysis of Particle Kinetics Problems via Equation of Motion

When a problem is slightly more involved, a thorough analysis is often helpful to our MET students to fully understand the problem and its solutions.

Shown in Fig 6 is an example. A small block B is supported by a platform connected at A to rod OA. Point A describes a circle in a vertical plane at the constant speed v_A, while the platform is constrained to remain horizontal throughout its motion by the use of special linkage (not shown in the figure). The coefficient of friction between the block and the platform is $\mu_s = 0.40$. Determine (a) the maximum allowable speed v_A if the block is not to slide on the platform, (b) the values of θ for which sliding is impending.

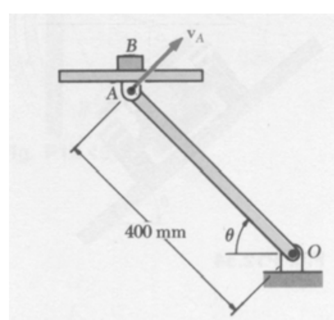

Fig 6. A problem of curvilinear translation

The normal analytical approach to this problem has two steps. In the first step, using the x- and the y- components (or the normal and the tangential components) of the equation of motion, an equation of maximum velocity v_A without sliding is found as

$$(\max V_A)^2 = \mu_s g\, \rho / (\cos\theta + \mu_s \sin\theta) \qquad (1)$$

where g is the gravitational acceleration, ρ is the radius of curvature, θ is the angle of crank OA as shown in the Fig 6, and max V_A is the velocity permissible by the friction for the particular crank angle θ. In the second step, the minimum of $(\max V_A)^2$ and the corresponding θ are found using calculus or Excel Solver. Here the above two sentences must be written carefully to tell what is maximized and what is minimized. The same possible confusion can arise in the students.

Therefore, in addition the above analytical analysis, the author also asks the students to plot the curve of max V_A versus θ as in Equation (1). With the plot, the students get a picture of what is meant by the minimum of the maximum.

Crank Angle *θ*		$(V_A)^2$	V_A
deg	radian	$(m/s)^2$	m/s
0	0.000	1.569	1.253
1	0.017	1.558	1.248
2	0.035	1.548	1.244
3	0.052	1.539	1.241
4	0.070	1.530	1.237
5	0.087	1.522	1.234

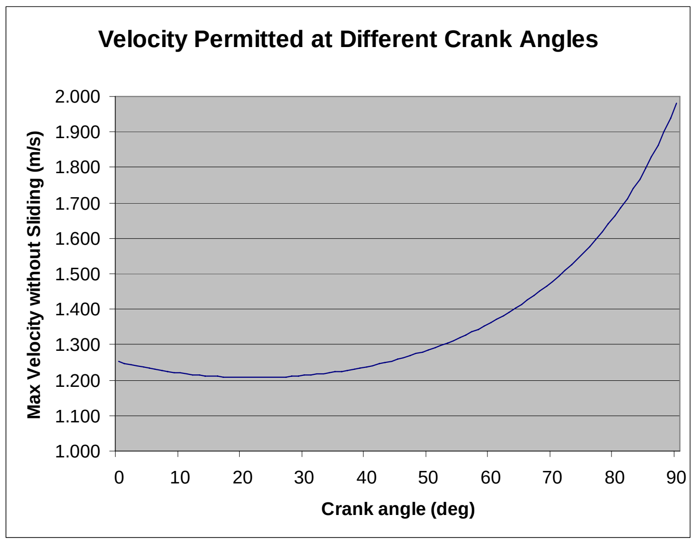

Fig 7. Using an Excel graph to illustrate the concepts of the problem in Fig 6

Further Study of Particle Kinetics Problems via Energy Methods

Analysis via Excel tables and graphs can well help with study of energy transfer, balance and conservation.

Here is a problem in Fig. 8. A 12-lb collar slides without friction along a rod that forms an angle of 30° with the vertical. The spring is unstretched when the collar is at A. If the collar is released from rest at A, determine the value of the spring constant k for that the collar has zero velocity at B.

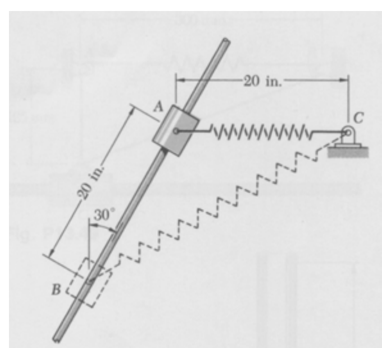

Fig 8. A problem of the energy method

The common algebraic approach is to write the potential energy of collar at B as a function of the spring constant k and to find the value of k that makes the total energy at B be equal to the total energy at A.

For the students to gain a deeper understanding of the concepts of energy transfer and conservation from this problem, in addition to the above solution, the author asks the students to table and plot the gravitational energy, the spring energy, the total potential energy, the total mechanical energy and the kinetic energy of the block in a series of positions from A to B. Tables and plots are made with different spring constants. Shown below are a top part of the table and the plots in which the spring constant is from the analytical solution.

Displ. down the rod	Gravitational potential energy	Spring Length Square	Spring Length	Spring potential energy	Total potential energy	Total Energy	Kinetic Energy
S	PE_{grav}	$(L_{spring})^2$	L_{spring}	PE_{spring}	PE_{total}	E	KE
(inch)				(lb-in)			
0	207.846	400	20	0.000	207.846	207.846	0.000
1	197.454	421	20.5	0.260	197.714	207.846	10.132
2	187.061	444	21.1	1.113	188.174	207.846	19.672
3	176.669	469	21.7	2.660	179.330	207.846	28.517
4	166.277	496	22.3	5.001	171.278	207.846	36.568

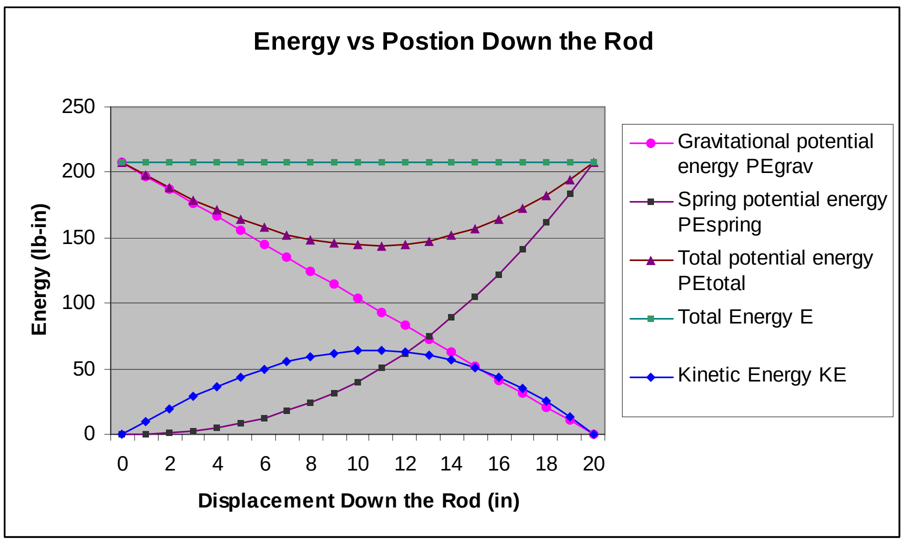

Fig 9. Using an Excel table with a graph to illustrate solutions of the problem in Fig. 8

Conclusions

The paper has indicated with a number of examples that engineering analysis extended from original problems can help students better understand the concepts and the methods in the course of engineering dynamics. The analysis can better prepare students for future applications since it addresses some valid comments from an alumni survey. Microsoft Excel has so far been used a main tool in the engineering analysis.

References

[1] Beer, Ferdinand P., and E. Russell Johnson, Jr., "Mechanics for Engineers – Dynamics," McGraw-Hill.

[2] Solid Edge, UGS Company

ZHONGMING (WILSON) LIANG is an associate Professor of Mechanical Engineering Technology in Purdue University Fort Wayne.