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AUTHOR Zahraee, Mohammad A.; And Others
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ABSTRACT

This paper discusses two software packages used in kinematics courses at Purdue University, Calumet (Indiana) and some algorithms written by students for cam design. The first software package, 4BAR, requires the user to define the particular four bar linkage in terms of lengths of the individual links and the angle and distance to the coupler point. Once the linkage has been defined, the user is free to select different options which will analyze various aspects of the linkage. The options are as follows: (1) coupler curve point; (2) table of output; (3) transmission angle; (4) animation; (5) position; (6) velocity; and (7) acceleration. The second software package, CADAM, allows the user to test the motion of a mechanism to verify that it works as designed. The program allows the user to construct and modify mechanisms, delete existing linkages, animate the motion of the mechanism, and display the motion coordinates of the mechanism on a graph or table. Figures and graphs are included to show some of the capabilities of both software packages. A sample of a computer project in which students were asked to write a computer program that could calculate and generate a cam profile is also included. The problem statement and a diagram that were part of the assignment and a computer program (in both BASIC and FORTRAN programing languages) are also provided. (KR)

COMPUTER SOFTWARE & PROGRAMING UTILIZATION IN KINEMATICS

Mohammad A. Zahraee, Gregory Neff, and Sham Tickoo
MET Program, Purdue University Calumet
Hammond, Indiana

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Mohammad A. Zahraee, Gregory Neff, and Sham Tickoo
MET Program, Purdue University Calumet
Hammond, Indiana 46323-2094

ABSTRACT

After building up a theoretical and graphical understanding of kinematics problems, a student's comprehension could be greatly increased when they run varying parameter examples and compare changes in responses.

Upon completion of chapters on velocity, acceleration, and linkages, the student simulates a linkage by means of a 4BAR linkage analysis program which has user friendly commands to enter the data and also good graphical displays of results.

Cam design and construction of a cam profile is a tedious job when done graphically by hand. Students are required to write a computer program in BASIC, FORTRAN or LISP to calculate and generate the CAM profile as a term project. Once done, they can study different profiles for their specific cam follower. This is followed by a class discussion and presentation.

In this paper, the methods and activities employed are discussed. Also, the possibility of using CADAM release 21.0 which now has the capability of solving kinematics problems is considered.

INTRODUCTION

The increasing demand for manufacturing automation has caused more emphasis to be placed on kinematic analysis and design of mechanisms. A good example is the recent research on Adjustable Robotic Mechanisms (ARMs) whose design is based on a simple planar mechanism, with adjustable lengths[1]. There are computer software packages available, some with graphics. Although each software package has its own limitations, a good choice of software package provides enough insight for students so that they could develop their own algorithms at a later time.

Software packages are useful but limited. We believe that students should be able to develop their own algorithms as well as being able to use general purpose software. This is not just to give students more training in computer programming, although it does. In the real world, a student may need to write his own program for design using the company's standards or data bank.

Today, nearly every engineering/technology curriculum teaches a graphics/drafting package to the beginning freshman. Kinematics is offered in both engineering and engineering technology curriculums. Graphical approaches are more popular in technology programs than engineering. It is a very good practice to have students use computer software even when using graphical methods. Once the drawings are done on a computer, for example, the vectors can be measured exactly, The polygons can be drawn more quickly and getting exact results in a shorter time makes the course more interesting for students.

The following sections of this paper discuss the software packages used in the kinematics course in our depatment at Purdue Calumet as well as some algorithms written by students for cam design.

SOFTWARE PACKAGES

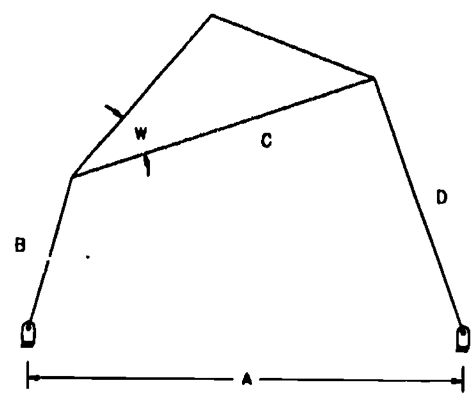
Besides AutoCAD software that our students use to draw the velocity and acceleration polygons throughout the course, In the past we have used two other off the shelf software packages that are discussed below.

4BAR Program

After the course introduction, students are immediately introduced to four bar linkages. This is a very important part of kinematics since many mechanisms can conveniently be replaced by a four-bar linkage or a combination of four bar linkages for the purpose of analyzing their motion.

Different motions could result depending on the proportions of the links within a linkage. Examples are: Crank-rocker, Double crank, Double rocker, Drag link, etc. There are usually inequalities that should be satisfied for a four bar linkage to produce a specific motion. After a student has wrestled enough with these inequalities, it is a good idea to use a software package that could do the testing and animate the motion of the linkage. "4BAR" is a micro-computer based linkage analysis program[2] that does the above and a lot more.

This program requires that the user defines his/her particular four bar linkage in terms of lengths of the individual links and the angle and distance to the coupler point, as shown below:

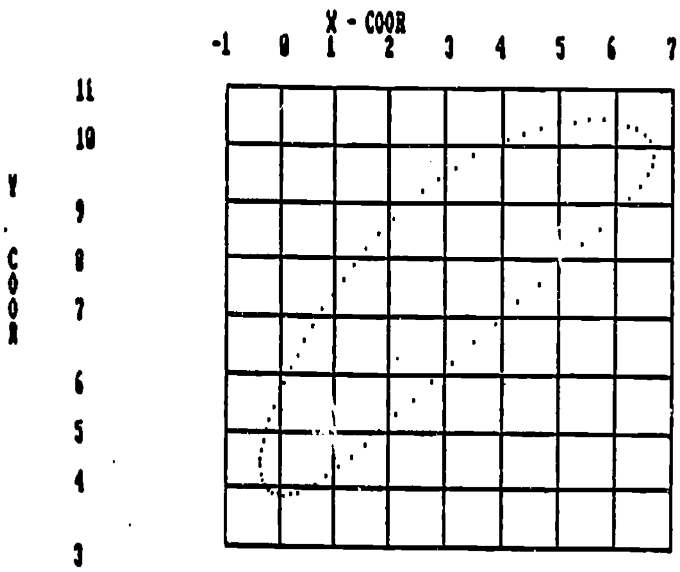


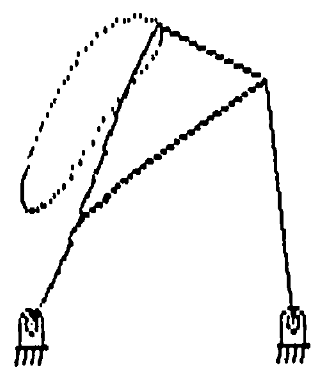
Link "B" corresponds to the input link and link "D" corresponds to the output link.

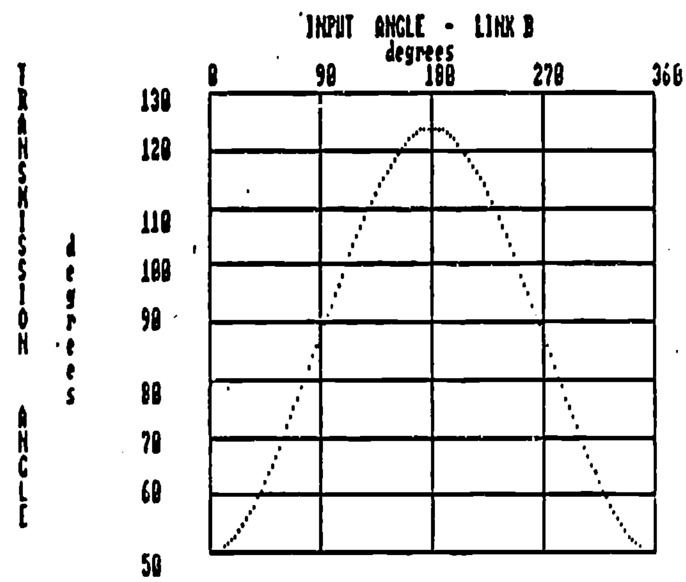
Once the linkage has been defined, the user is free to select different options which will analyze various aspects of the linkage. These options are as follows:
1) Coupler curve point, 2) Table of output, 3) Transmission angle, 4) animation, 5) Position, 6) velocity, 7) acceleration.

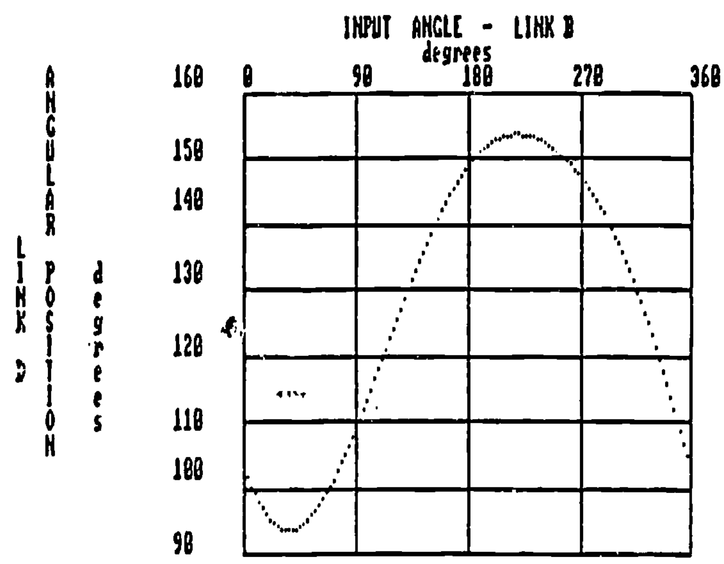
An interesting option of the program which is used at the beginning of the course is the animation. This option allows the student to visually "see" how the four bar mechanism will move. The input crank (link -B-) is rotated thru two complete cycles of rotation in increments of 5 degrees. The display is alternately drawn and undrawn, thereby producing the appearance of motion.

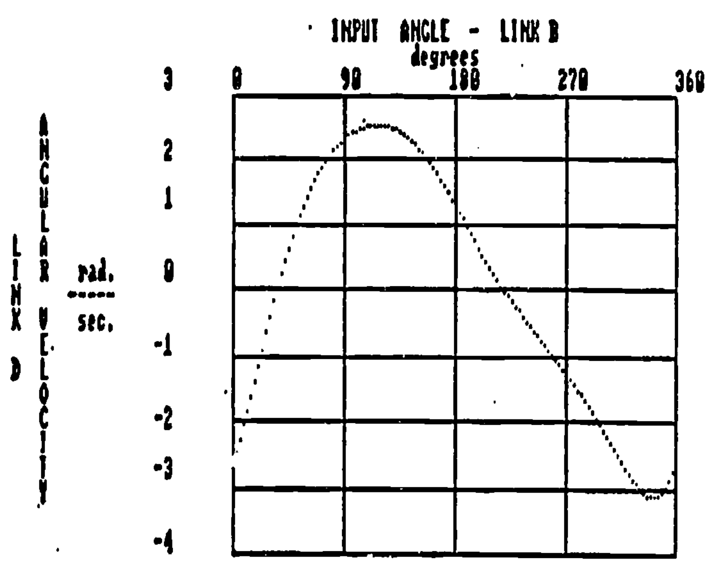
Some graphical and the tabular output from the program follow:

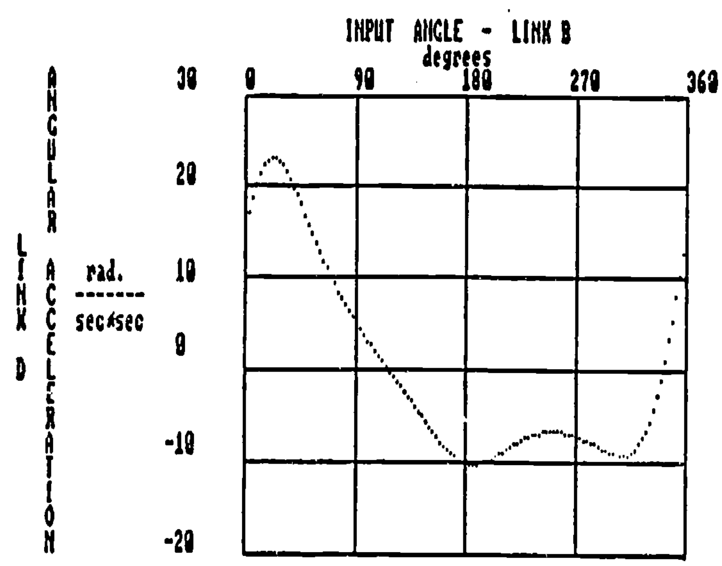












4 -BAR LINKAGE COMPUTED RESULTS

```
GROUND LINK=      1.2000E+01  INPUT LINK= 4.1250E+00  COUPLER LINK= 1.0000E+01
OUTPUT LINK= 8.2500E+00 DIST TO C.P=     8.0000E+00  ANGLE TO C.P= 3.0000E+01
INPUT CRANK VELOCITY= 5.0000E+00     INPUT CRANK ACCELERATION= 0.0000E+00
```

INPUT ANGLE	OUTPUT ANGLE	COUPLER POINT X	Y	TRANSMISSION ANGLE	OUTPUT VELOCITY	OUTPUT ACCELERATION
0.000E+00	1.034E+02	5.047E+00	7.947E+00	5.001E+01	-2.619E+00	1.483E+01
3.000E+01	9.387E+01	6.558E+00	9.485E+00	5.578E+01	-4.253E-01	2.219E+01
6.000E+01	9.740E+01	6.367E+00	1.032E+01	6.996E+01	1.432E+00	1.276E+01
9.000E+01	1.091E+02	4.976E+00	1.039E+01	8.755E+01	2.328E+00	4.915E+00
1.200E+02	1.240E+02	3.178E+00	9.617E+00	1.049E+02	2.540E+00	-7.056E-01
1.500E+02	1.384E+02	1.576E+00	8.186E+00	1.185E+02	2.177E+00	-6.274E+00
1.800E+02	-2.110E+02	4.477E-01	6.564E+00	1.239E+02	1.279E+00	-1.014E+01
2.100E+02	-2.065E+02	-1.961E-01	5.190E+00	1.185E+02	2.497E-01	-8.855E+00
2.400E+02	-2.075E+02	-3.424E-01	4.241E+00	1.049E+02	-5.563E-01	-6.847E+00
2.700E+02	-2.130E+02	7.270E-02	3.875E+00	8.755E+01	-1.271E+00	-7.208E+00
3.000E+02	-2.231E+02	1.089E+00	4.368E+00	6.996E+01	-2.126E+00	-9.125E+00
3.300E+02	-2.386E+02	2.793E+00	5.899E+00	5.578E+01	-3.009E+00	-5.536E+00
3.600E+02	1.034E+02	5.048E+00	7.947E+00	5.001E+01	-2.619E+00	1.483E+01

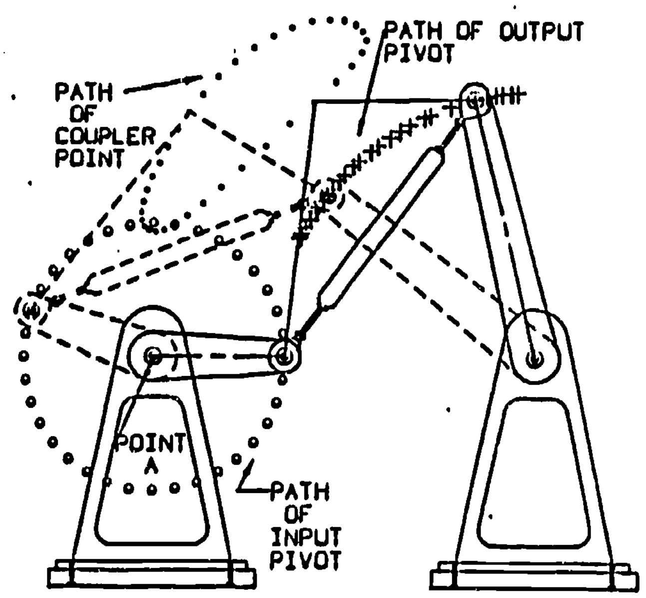
CADAM Software

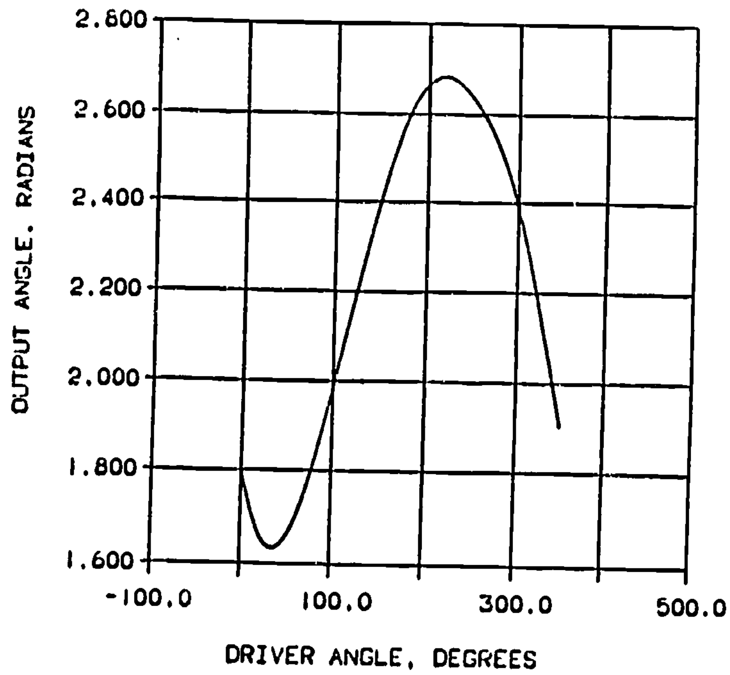
Once our students are familiar with 4-bar linkages, a class period is used to demonstrate the capabilities of mainframe CADAM software in solving kinematics problems. It is worth mentioning that our most popular elective course is *Computer Aided Design with Applications* which is offered every semester. A large percentage of students who take Kinematics have already had this CADAM course and feel comfortable with it. The current release of CADAM (Rel. 21.0) has added an engineering analysis feature a part of which is Kinematics[3].

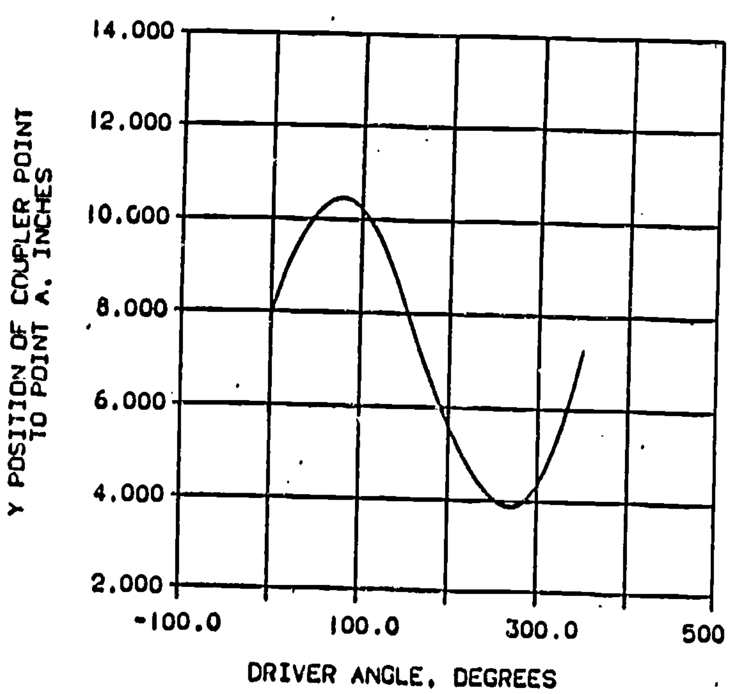
The kinematics feature allows the user to test the motion of a mechanism to verify that it works as designed. The advantage of this software is that one can construct a mechanism from a link, fourbar, fivebar, lazytong, actuator, track, slot, or cam. The program can handle a mechanism consisting of up to 24 total units including five drivers and up to 96 rider points. The program allows the user to construct and modify mechanisms, delete existing linkages, animate the motion of the mechanism, and display the motion coordinates (position, velocity, acceleration, and angle) of the mechanism on a graph or table.

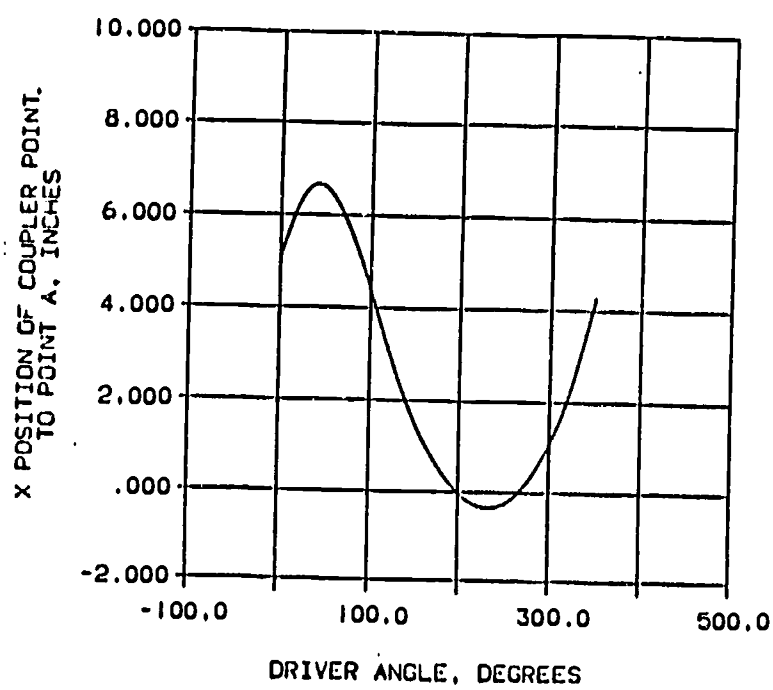
Since not all students are familiar with CADAM before taking the kinematics course, and the kinematic analysis feature requires the user to draw the mechanism first, optional extra credit projects are offered to those students who are interested in moving a step beyond and at the same time upgrade their course grade.

The following figure and graphs show some capabilities of the software. The same linkage that was solved using the 4-BAR program is used here so that the reader may compare the outputs of the two types of software. It should be noted that CADAM costs $8000 per year for software maintenance while the 4-BAR software is much more limited but much cheaper and easier to use.


PATH OF OUTPUT PIVOT
PATH OF COUPLER POINT
POINT A
PATH OF INPUT PIVOT


2.800
2.600
2.400
2.200
2.000
1.800
1.600
OUTPUT ANGLE, RADIANS
-100.0
100.0
300.0
500.0
DRIVER ANGLE, DEGREES


14.000
12.000
10.000
8.000
6.000
4.000
2.000
Y POSITION OF COUPLER POINT TO POINT A, INCHES
-100.0
100.0
300.0
500
DRIVER ANGLE, DEGREES


10.000
8.000
6.000
4.000
2.000
.000
-2.000
X POSITION OF COUPLER POINT TO POINT A, INCHES
-100.0
100.0
300.0
500.0
DRIVER ANGLE, DEGREES

COMPUTER ALGORITHMS

The simplest way of achieving almost any desired motion is through cam mechanisms. After introducing common types of follower motions, different methods of cam profile construction are taught in our kinematics course.

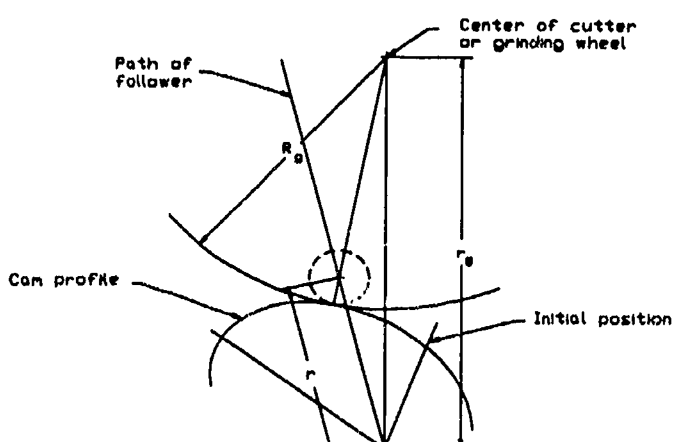
The graphical method for obtaining a cam profile is limited to low-speed cams where high accuracy is not required. For some cams, particularly high-speed cams, accurate profiles are required and mathematical analysis is necessary in order to obtain data for positioning the cutter relative to the cam.

At this point of the course, students are given a computer project in which each student is given two sets of data. One data set is common for all students and the other one is different and is randomly generated for each individual. Our students at Purdue Calumet take MET 161 in their first semester where they learn the BASIC programming language. They also take a FORTRAN programming language course in their fifth semester. In addition, they learn AutoLISP programming in their second CAD course which they take in their third semester. This versatility helps makes our kinematics course interesting. For their computer term project, students are given the option of writing their program using BASIC, FORTRAN or AutoLISP programing languages. Using AutoLISP, they could also generate their drawing directly and create IGES files that could be sent to a CNC machine where the cam could be advanced by a fraction of a degree and the cutter could be advanced by thousands of a millimeter.

The following is a sample computer project that was given to our students in Fall of 1990. The flow chart which was part of the assignment, and the program (in two languages) follow right after the problem statement. Once these assignments were done, each student discusses his/her findings on the cam profile and design limitations associated with their data.

Problem Statement:

For a disk cam with roller follower, the displacement diagram, base circle radius, roller radius, and cutter radius are known. Write a computer program to compute the values for the grinder radius and angle (refer to the figure). The program should also calculate the pressure angle. Each of the following types of motion should be handled by the program: a) Constant acceleration, b) Simple harmonic, and c) Cycloidal.



Basic Program

```
10 DIM A$(30)
20 PI=3.14159265
30 PRINT :PRINT "INPU' TOTAL RISE OF FOLLOWER ";:INPUT H
40 PRINT :PRINT "INPU . BETA IN DEGREES ";:INPUT ZBETA
50 PRINT :PRINT "INPUT INCREMENTS FOR THETA IN DEGREES ";:INPUT INCR
60 PRINT :PRINT "INPUT BASE CIRCLE RADIUS ";:INPUT RB
70 PRINT :PRINT "INPUT CUTTER RADIUS ";:INPUT RG
80 PRINT :PRINT "INPUT ROLLER RADIUS ";:INPUT RR
90 REM ** CALCULATE: GRINDER RADIUS
91 REM *          GRINDER ANGLE
92 REM *          PRESSURE ANGLE
93 REM
94 OPEN "CAMANS.DOC" FOR OUTPUT AS #1
95 REM
96 REM ****************************
97 REM ** CONSTANT ACCELERATION **
99 REM ****************************
100 A$="CONSTANT ACCELERATION"
105 GOSUB 2000
110 FOR ANG=0 TO ZBETA STEP INCR
120 THETA=ANG*PI/180
125 BETA=ZBETA*PI/180
130 IF THETA/BETA<0.5 THEN S=2*H*(THETA/BETA)^2 ELSE S=H*(1-2*(1-THETA/BETA)^2)
140 IF THETA/BETA<0.5 THEN DS=(4*H*THETA)/(BETA*BETA) ELSE DS=(4*H/BETA)*(1-
THETA/BETA)
160 GOSUB 1010
170 NEXT ANG
180 GOTO 300
296 REM
297 REM **********************
298 REM ** SIMPLE HARMONIC **
299 REM **********************
300 A$="SIMPLE HARMONIC
305 GOSUB 2000
310 FOR ANG=0 TO ZBETA STEP INCR
320 THETA=ANG*PI/180
325 BETA=ZBETA*PI/180
330 S=H/2*(1-COS(PI*THETA/BETA))
335 DS=PI*H*SIN(PI*THETA/BETA)/(2*BETA)
340 GOSUB 1010
350 NEXT ANG
396 REM
397 REM ***************
398 REM ** CYCLOIDAL **
399 REM ***************
400 A$="CYCLOIDAL"
405 GOSUB 2000
410 FOR ANG=0 TO ZBETA STEP INCR
420 THETA=ANG*PI/180
425 BETA=ZBETA*PI/180
430 S=H*(THETA/BETA-(1/(2*PI))*SIN(2*PI*THETA/BETA))
```

```
435 DS=(H/BETA)*(1-COS(2*PI*THETA/BETA))
440 GOSUB 1010
450 NEXT ANG
900 REM
945 REM ************************
946 REM ** END OF THE PROGRAM **
947 REM ************************
950 END
996 REM
997 REM *************************
998 REM ** CALCULATE THE CHART **
999 REM *************************
1010 R=RB+S
1020 PRANG=ATN(DS/R)
1030 RGG=SQR(R^2+(RG-RR)^2+2*R*(RG-RR)*COS(PRANG))
1040 ETAS=(RG-RR)*SIN(PRANG)/RGG
1050 ETA=ATN(ETAS/SQR(1-ETAS^2))
1053 PSI=THETA-ETA
1057 TB=THETA/BETA
1059 REM * CUT TO 3 DECIMAL PLACES
1060 S=INT(S*1000+0.5)/1000
1061 PRANG=PRANG*180/PI
1062 PRANG=INT(PRANG*1000+0.5)/1000
1063 RGG=INT(RGG*1000+0.5)/1000
1065 PSI=PSI*180/PI
1066 PSI=INT(PSI*1000+0.5)/1000
1068 TB=INT(TB*1000+0.5)/1000
1070 PRINT #1,ANG,TB,S,RGG,PSI,PRANG
1080 RETURN
1998 REM
1999 REM ****************************
2000 REM * PRINT THE CHART HEADINGS *
2001 REM ****************************
2005 PRINT #1,A$
2020 PRINT #1,"THETA","THETA","S ","CENTER","GRINDER","PRESSURE"
2030 PRINT #1,"    ","/BETA"," "," DIST."," ANGLE "," ANGLE "
2040 PRINT #1," deg ","    ","mm"," mm  "," deg "," deg "
2050 RETURN
```

Sample Program Output:

CONSTANT ACCELERATION

THETA deg	THETA /BETA	S mm	CENTER DIST. mm	GRINDER ANGLE deg	PRESSURE ANGLE deg
0	0	0	114	0	0
5	.067	.178	114.147	4.134	2.909
10	.133	.711	114.59	8.292	5.765
15	.2	1.6	115.335	12.497	8.519
20	.267	2.844	116.39	16.768	11.129
25	.333	4.444	117.766	21.118	13.563

30	.4	6.4	119.475	25.556	15.798
35	.467	8.711	121.526	30.088	17.823
40	.533	11.289	124.157	35.316	17.35
45	.6	13.6	126.788	41.114	14.637
50	.667	15.556	129.003	46.85	12.035
55	.733	17.156	130.808	52.536	9.522
60	.8	18.4	132.207	58.183	7.081
65	.867	19.289	133.204	63.804	4.692
70	.933	19.822	133.801	69.406	2.337
75	1	20	134	75	0

SIMPLE HARMONIC

THETA deg	THETA /BETA	S mm	CENTER DIST. mm	GRINDER ANGLE deg	PRESSURE ANGLE deg
0	0	0	114	0	0
5	.067	.219	114.172	3.941	3.559
10	.133	.865	114.692	7.964	6.883
15	.2	1.91	115.561	12.138	9.772
20	.267	3.309	116.772	16.505	12.084
25	.333	5	118.303	21.086	13.741
30	.4	6.91	120.106	25.876	14.715
35	.467	8.955	122.111	30.862	15.02
40	.533	11.045	124.233	36.02	14.69
45	.6	13.09	126.372	41.326	13.777
50	.667	15	128.42	46.756	12.341
55	.733	16.691	130.273	52.286	10.451
60	.8	18.09	131.833	57.896	8.184
65	.867	19.135	133.014	63.565	5.624
70	.933	19.781	133.75	69.273	2.863
75	1	20	134	75	0

CYCLOIDAL

THETA deg	THETA /BETA	S mm	CENTER DIST. mm	GRINDER ANGLE deg	PRESSURE ANGLE deg
0	0	0	114	0	0
5	.067	.039	114.035	4.718	.946
10	.133	.301	114.254	8.929	3.602
15	.2	.973	114.772	12.805	7.428
20	.267	2.168	115.675	16.61	11.606
25	.333	3.91	117.052	20.611	15.277
30	.4	6.129	118.957	24.99	17.792
35	.467	8.672	121.35	29.814	18.822
40	.533	11.328	124.068	35.061	18.311
45	.6	13.871	126.851	40.658	16.407
50	.667	16.09	129.403	46.505	13.415
55	.733	17.832	131.465	52.48	9.787

60	.8	19.027	132.885	58.446	6.085
65	.867	19.699	133.666	64.262	2.903
70	.933	19.961	133.959	69.808	.757
75	1	20	134	75	0

FORTRAN Program

The following algorithm is a sample FORTRAN program for the same problem. To avoid repetition, the output of the program which is quite similar to that of the BASIC progrm is not shown.

```
C       PROGRAM CAM
        PROGRAM CAM (INPUT,OUTPUT,TAPE10=INPUT,TAPE20=OUTPUT)
        READ(10,30)MOTION,H,BETA,RB,RADG,THETAIN,THETAFI,OINCRMT
       +,RG,RR
   30   FORMAT(A10,9F10.7)
        THETA=THETAIN
        PI=3.14159265
        WRITE(20,40) MOTION
   40   FORMAT(*1*,5x,A10)
        IF ( MOTION.EQ.8HCONSTANT) WRITE(20,50)
   50   FORMAT(***,14X,*ACCELERATION*)
        WRITE (20,60)
   60   FORMAT(*-      THETA      THETA/BETA      S      Q      R    E
       +TA      PSIG      RG      PHI      RGG*)
        WRITE (20,70)
   70   FORMAT(*       DEG*,18X,*MM     MM       MM      DEG      DE
       +G      MM      DEG      MM*)
   80   IF (MOTION.EQ.8HHARMONIC) GO TO 100
        IF (MOTION.EQ.9HCYCLOIDAL) GO TO 110
        IF (THETA/BETA.GT.0.5) GO TO 90
        S=2.*H*(THETA/BETA)**2
        Q=4.*H*(THETA/BETA/(BETA*PI/180.)
        GO TO 120
   90   S=H*(1.-2.*(1.-THETA/BETA)**2)
        Q=4.*H*(1.-THETA/BETA)/(BETA*PI/180.)
        GO TO 120
  100   S=H*(1.-COSD(180.*THETA/BETA))/2.
        Q=PI*H*SIND(180.*THETA/BETA)/2./(BETA*PI/180.)
        GO TO 120
  110   S=H*(THETA/BETA-SIND(360.*THETA/BETA))/(2.*PI)
        Q=H*(1.-COSD(360.*THETA/BETA))/(BETA*PI/180.)
  120   R=RB+S
        PHI=ATAN)DS/R)
        RGG=SQRT(R**2+(RG-RR)**2+2*R*(RG-RR)*DCOS(PHI)
        ETA=SIND(PHI)*((RG-RR)/RGG)
        PSIG=THETA-ETA
        WRITE(20,130)THETA,THETA/BETA,S,Q,R,ETA,PSIG,RG,PHI,
       +RGG
  130   FORMAT(*-*,F10.2,F10.4,8F10.3)
        THETA=THETA+OINCRMT
        IF (THETA.LE.THETAFI) GO TO 80
        END
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AutoLISP Program

As an option for their computer term project, students can choose to use the AutoLISP language which is supported by AutoCAD software. The advantage is that the cam profile could be generated directly. Once the profile is generated, it is converted to DXF (Drawing Interchange File) format. In a kinematics course, because of the limitations on the time that could be spent on the subject of cams, one can at most write the routine and generate the cam profile on screen and send it to plotter. Our students, though, can later use this program in another elective course called MFET 461, *Manufacturing Applications of Computers*. In this course, they can transfer their cam profile DXF file (or other drawings created by AutoCAD) to GeoPath, a computer Aided Manufacturing software package, where they enter the tooling information and simulate the tool path. They then load the program on the Bridgport CNC machine to cut the profile usually using Plexiglass material. The AutoLISP program seems rather more complicated than the preceeding two programs and for this reason, only one student has tried it in the past. The procedure mentioned above, and the algorithm itself, is the subject of a forthcoming brief publication and therefore is not shown here.

CONCLUSIONS

In today's competetive technological world, avoiding computer usage in a design or analysis course will put the graduating student in an awkward position. Available software packages should be used to speed up the procedure used in analysis and create more examples for students to see design limitations and experience parametric studies instead of repeating tedious procedures by hand. However, students should be asked to create their own algorithms in order to be able to respond to the specific needs of industry they will work for in the future.

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