A Windows-Based Software for Analysis of Mechanisms and Machinery

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ABSTRACT   .

A novel PC-based software package is introduced for the analysis of planar mechanisms and machinery. The package is written in Visual Basic Ver. 6.0, to be compiled and run on IBM and compatible personal computers under Windows 95 or later versions. The package capitalizes on the fact that a large class of machinery and mechanisms is composed of either single or multiple basic linkages comprising the slider-crank mechanism, the four-bar linkage and their inversions. The software can analyze composite mechanisms consisting of up to ten basic linkages.

A significant advantage of the software is the fact that it provides the user with a comprehensive set of information on the kinematics and dynamics of not only the members of a simple or combined mechanism, but also of specified points on the mechanism. Thus the user is supplied with exhaustive information on all ground reactions as well as joint forces and other required force, torque and kinematic unknowns.

The software features animation capabilities along with the ability to trace the paths of selected points. All kinematic and dynamic output data is readily transferred to Microsoft Excel for further processing.

KEYWORDS

Animation, dynamics, kinematics, linkage, mechanism, reactions, trace.

1.   INTRODUCTION

The advent of high-speed digital computers in the last two decades has changed many aspects of engineering analysis and design, and has opened new options in the study of machinery. Analysis and design of machinery is a tedious process that, almost always, involves displacement and kinematic analyses followed by a study of the dynamic characteristics of the machine under realistic working conditions. The amount of repetitive work that is involved in this process of design and analysis is indeed considerable. There is no reason why much of this pedagogically

insignificant labor can not be assigned to the computer. There is general consensus that time is ripe to explore the possibility of bringing the computer into the classroom at the undergraduate level, and to take advantage of its capabilities during lectures, tutorials and examinations. With the advent of electronic computers, it was the mechanical engineers who were very eager to use them to minimize the drudgery in analysis and design work. Numerous software packages have been developed to date for the analysis of mechanisms and machinery. Most of these require specialized equipment, including a mainframe computer or a workstation. The number of mechanisms programs that can be run on a PC are still meager, and these are on the relatively weaker side of the spectrum. The reader is referred to references [1] and [2] for general reviews in this regard.

In an effort to bring the computer into the classroom, and also to do away with the aging manual techniques in mechanism analysis, work was initiated by the second author in 1984. At first, simple kinematics programs that can be run on a pocket computer were introduced in BASIC. These programs were further strengthened later, and dynamic effects were subsequently introduced. Although memory requirements did increase, suitable pocket computers were still available in student-affordable price ranges. The current version of the resulting DOS program [3] is capable of analyzing the general four-bar linkage and its various inversions. It is possible to treat these mechanisms alone or in combinations. Called *Al-Yaseer*, this program also features modest animation capabilities. A major advantage of *Al-Yaseer* is the fact that it provides the user with a comprehensive set of information on the kinematics and dynamics of not only the links but also of specified points on these members. The reader is referred to references [3] and [4] for more complete discussions on this software.

In what follows, a brief introduction is presented to the as yet un-released Windows version of the software (*Al- Yaseer* 2.0). The new package is written in Visual Basic Ver. 6.0. The SI system is used throughout. Force analyses require that distances are in meters, masses in kg, centroidal mass moments of inertia in kg-m², forces in Newtons, and couples, torques and moments are in N-m.

2.   AL-YASEER PACKAGE

For the purpose of introducing *Al-Yaseer,* and illustrating its use within the constraints of space, consider the single-cylinder compressor shown schematically in Fig. 1. Table 1 summarizes the

Table 1. Basic Information on the Compressor

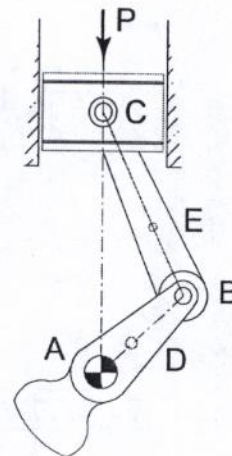|	crank AB	connecting rod BC	piston C
length - m	0.06	0.20	-
mass - kg	0.25	0.18	0.29
distance to center of mass - m	0.00	CE = 0.12	-
inertia (kg-m²)	7.5E-5	6E-4	-

Fig. 1. The compressor.

given data for crank AB, the connecting rod BC and the piston C. Note that the center of mass D of crank AB is located at A, and the center of mass of the connecting rod is at E. The compressor is to be driven tawafwise (counter clockwise) at the constant speed of 1350 rpm by a motor that supplies a uniform torque of 25 N-m. It is required to determine the trace of E, admissible gas forces P on the piston, as well as bearing forces at A, B and C.

Figure 2 shows the logo of *Al-Yaseer*. When the *main menu* appears (Fig. 3), the user is offered four choices in basic linkages, i.e., the slider-crank mechanism (Fig. 3a), the first inversion of the slider-crank mechanism (FISC), which is shown in Fig. 3b, the four bar linkage (displayed in Fig. 3), and the second inversion of the slider-crank mechanism (SISC), which is shown in Fig. 3c. The *main menu* also provides background information on Al-Yaseer (*About*), the possibility to exit the program (*Exit*), and also shows the way to proceed with the analysis (*Next*).
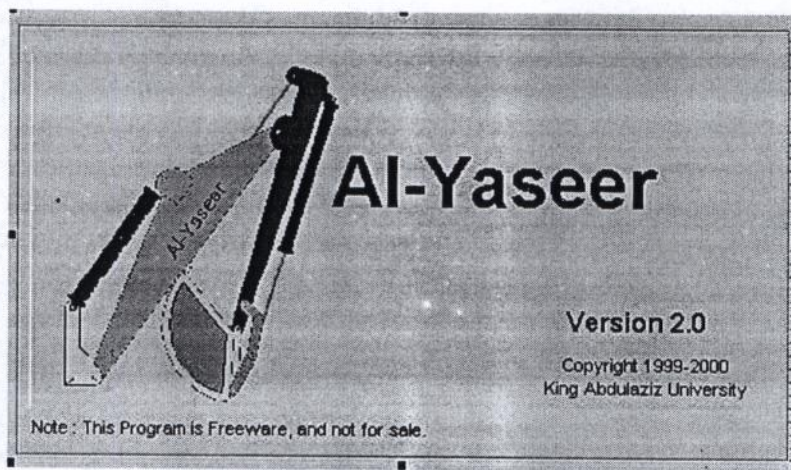

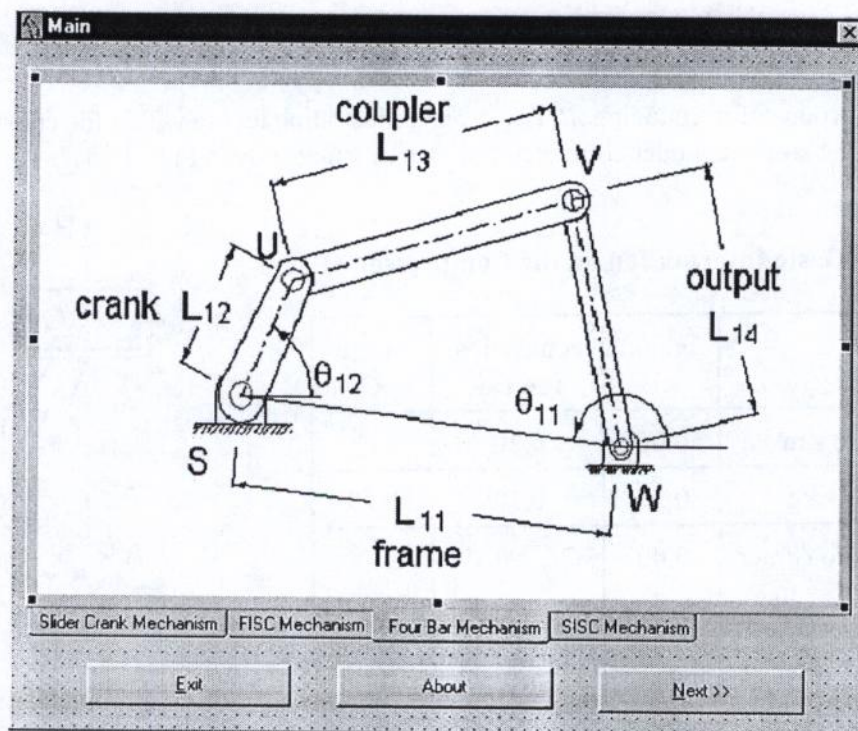Fig. 2. The logo of *Al-Yaseer* 2.0

Fig. 3. The main menu.

For the present case, the *slider-crank mechanism* would be selected in the main menu of Fig. 3, since the basic mechanism corresponding to Fig. 1 is a slider-crank mechanism. This action leads to the *input information form* (Fig. 4) for the slider-crank mechanism. The input information form is provided with five selection buttons at the top. These are a) dimensions, b) velocities and accelerations, c) rigid extensions, d) masses and moments of inertia, and e) forces. Pressing each one of these buttons causes the opening of a particular input information window of its own. Thus Fig. 4 shows the window for basic *input dimensions* for the slider-crank mechanism, where crank length L_2 (L2) is entered as 0.06m and the length of the connecting rod, L_3, is set to 0.2m. It is to be pointed out that, as the value for each variable is entered into the space provided, a contact-sensitive help box at the right side of the screen automatically displays basic information concerning that particular variable.

Since the mechanism is centric in the case of the compressor, offset L_1 is zero. This condition may be indicated by simply leaving the space for the magnitude of L_1 blank. The orientation of the cylinder axis is specified by writing the angle θ_4 (Theta4) of the axis of the cylinder (90° here) in the space provided.
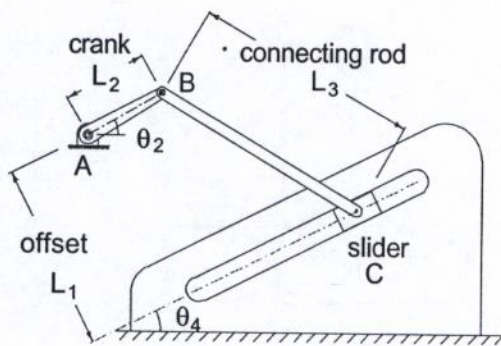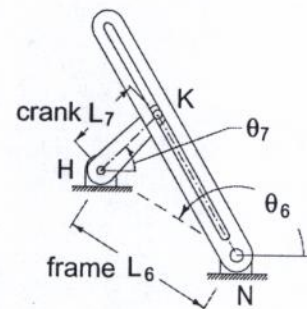

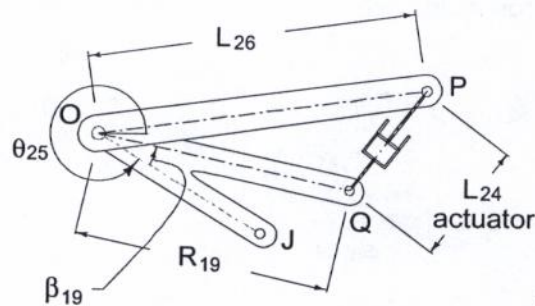Fig. 3a. The slider-crank mechanism.

Fig. 3b. The FISC mechanism.

Fig. 3c. The SISC mechanism.

The next button of input information is that of *velocities and accelerations*. Here the crank speed is entered as 1350 rpm. The angular acceleration of the crank is left blank, since the angular speed is given as constant.

The next button in the *input information form* is that of *rigid extensions* (Fig. 5). Polar coordinates are used in *Al-Yaseer* to specify the coordinates of any point on a link. The user needs to input a relative distance R and a relative angle θ to designate a given point. Thus, in the case of the slider-crank mechanism, radial distances R_1 and R_4, and relative angles θ_1 and θ_4 enable the computation of displacements, velocities, accelerations as well as traces of points lying on the
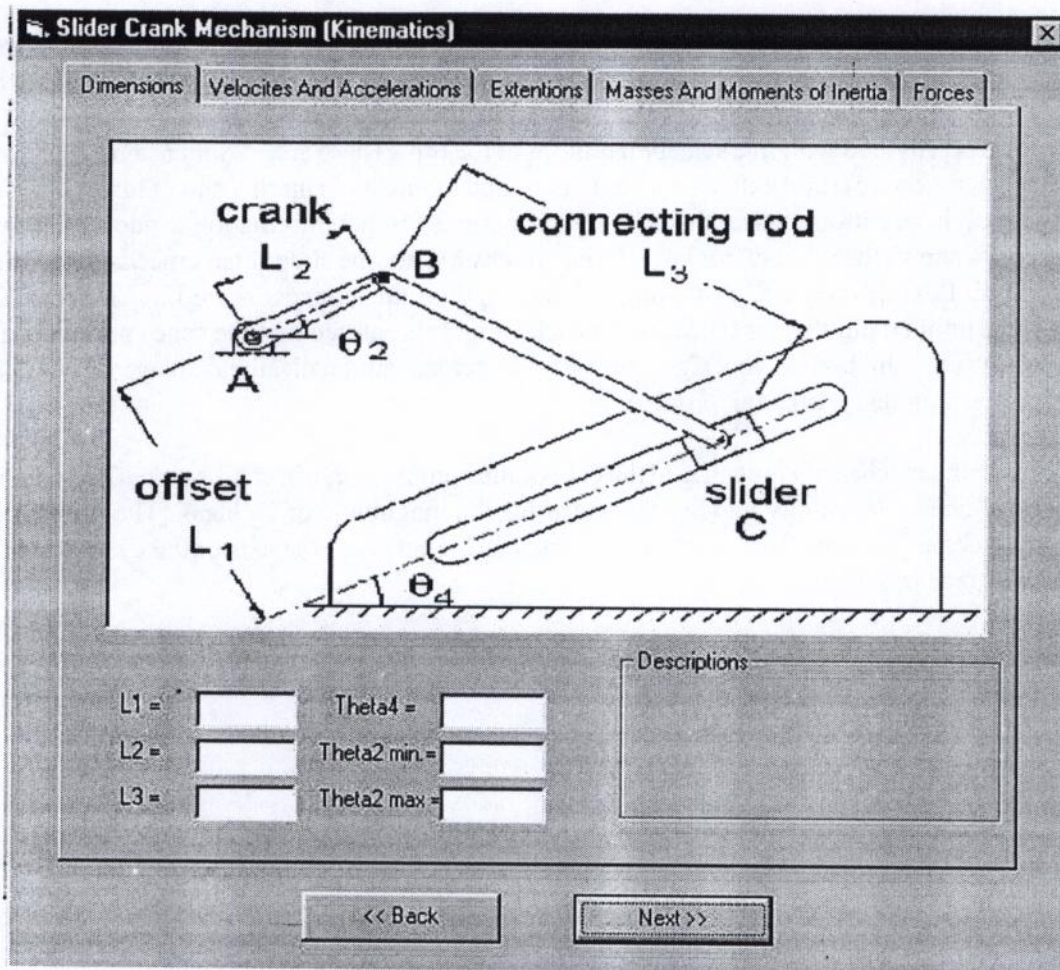
Fig. 4. *Input information form* for the slider-crank mechanism.
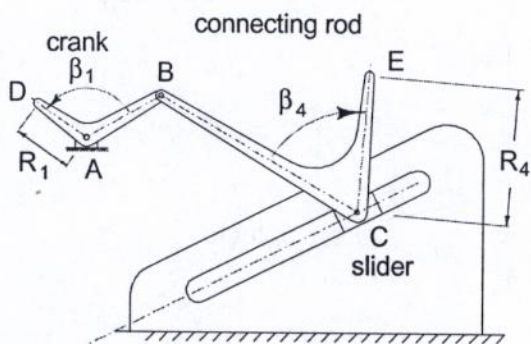

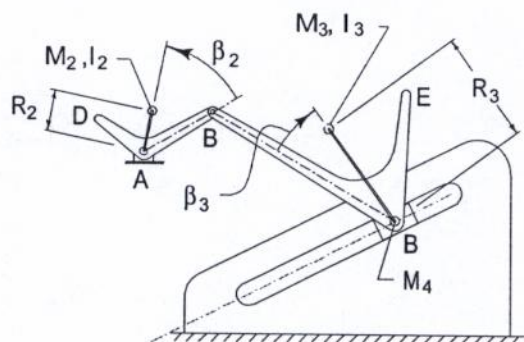Fig. 5. Rigid extensions of the slider-crank mechanism.

Fig. 6. Masses and moments of inertia of the slider-crank mechanism.

crank and its extensions, and the connecting rod and its rigid extensions. Since a trace of the center of mass E (Fig. 1) of the connecting rod is required in the present case, the location of E on the connecting rod needs to be specified. This is accomplished by setting R_4 in Fig. 5 to 0.12, and $\square_4 = 0$.

Magnitudes of *masses and moments of inertia* as well as their locations are entered next (Fig. 6). The center of mass of the crank is located by specifiying R_2 and $\square_2$, and that of the connecting rod

by R_3 and $\square_3$. In the present case the crank is balanced such that $R_2=0$. Referring to Table 1 and Fig. 6, it may be concluded that non-zero magnitudes in this form are $M_2 =0.25$, $I_2=7.5E-5$, $M_3=0.18$, $I_3=6E-4$, $R_3=0.12$ and $M_4= 0.29$, where M_4 designates the mass of the piston..

The last button in the *input information form* is for the specification of *known forces and moments* (Fig. 7). Here the input torque that is applied on the crank shaft is specified as $T_1=25$. The rest of the forces and angles on this form are left blank since they are not known.
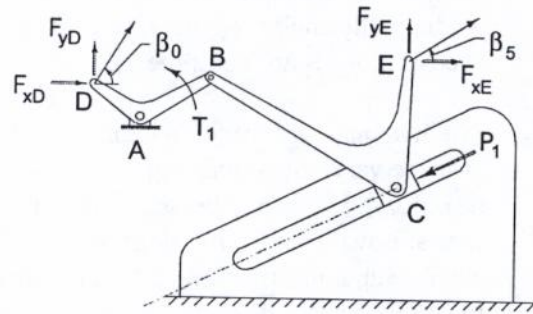

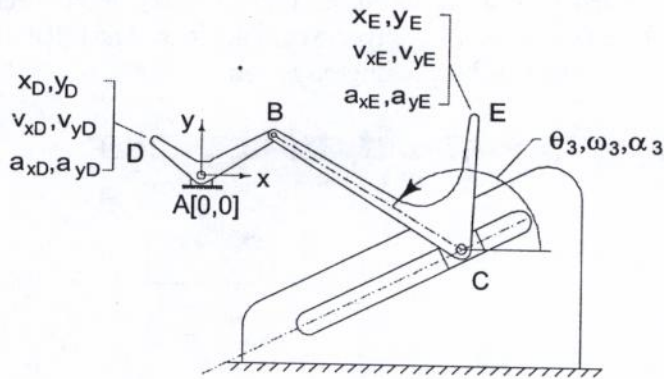Fig.7. Specification of known forces and moments in the slider-crank mechanism.

Fig. 8a. Output information resulting from the kinematic analysis of the slider-crank mechanism.

Fig. 8b. The *Output data form* for the kinematic analysis of the slider-crank mechanism.

Pressing the *next* button at the bottom of the *input information form* commences the calculations for *kinematics*. At this stage, and following a brief pause for computations, the *output information* depicted in Fig. 8a for kinematic computations is displayed in the form of an output table (Fig. 8b). It may be noted in Fig. 8a that linear displacements, linear velocities and linear accelerations of selected points on the crank and connecting rod are automatically computed. Thus x_E and y_E represent, relative to a coordinate system located at the crank shaft, the coordinates of point E on the rigid extension of the connecting rod. Similarly v_{xE} and v_{yE} are components of the linear velocity of point E, and a_{xE} and a_{yE} the components of its acceleration. Additionally angle θ_3 (Theta3) of the connecting rod as well as its angular velocity ω_3 and angular acceleration α_3 are computed.

The kinematic information depicted in Fig. 8a are tabulated in the *Output Data* form (Fig. 8b) as these vary with crank angle. The *output data form* offers a possibility to go to *Excel*, as may be observed at the top center of the form, for further processing of the output data. Other options that are available at this stage are, as displayed at the bottom of the form, a)to go *back* and change input information, b)to *animate* the mechanism and c)to *connect* the mechanism at hand to another basic linkage. It is to be noted that, up to ten basic linkages may be connected together in various ways to obtain combined mechanisms of diverse complexities. The last option available on this form is to commence force analysis by clicking on *forces*.
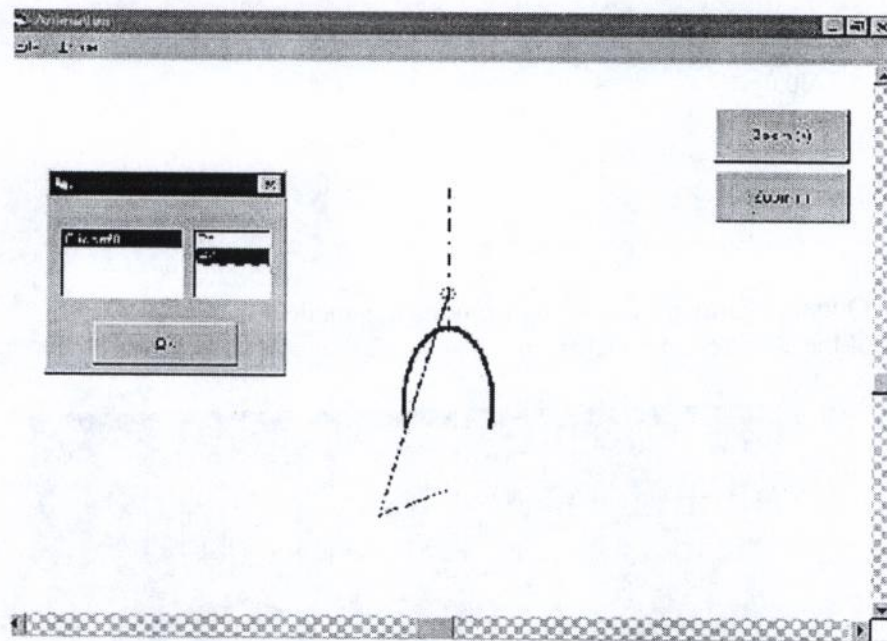

Fig. 9. The *Animation and trace* form.

Fig. 9 shows the *animation and trace* form, which appears when *animation* is selected on the *output data* menu. Notice in Fig. 9 that the compressor is depicted in the form of a stick diagram, with the axis of the cylinder being indicated with the vertical centerline. The piston is shown by the small circle located on the centerline. The crank is rotated, and the compressor is animated through its entire cycle continuously. The two *zoom bottons* located at the top right of the menu allow the stepless *zooming-in* or *zooming-out* of the animated figure while the animation process is going on. Tracing of one or more points of interest on the animated figure is made possible by clicking on *trace* at the left top of the form. A small trace window then appears, offering the user

a number of choices. In the present case, R_4 is selected, since the location of E, the trace of which is sought, is determined by setting $R_4 = 0.12$.
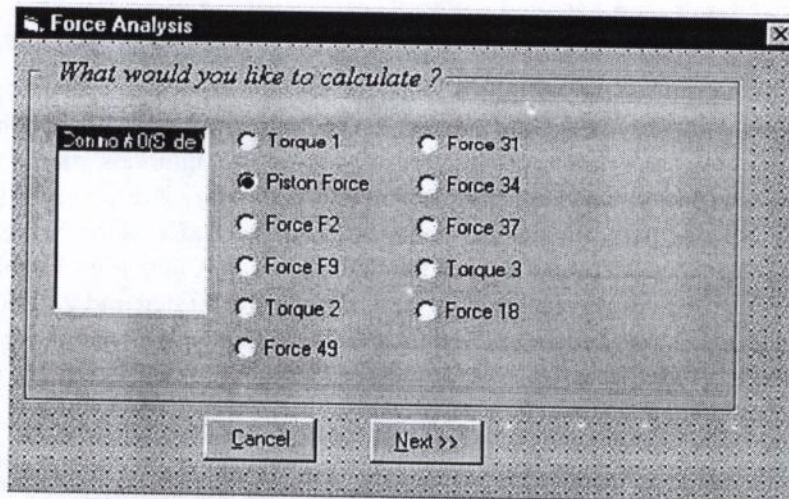

Fig. 10. The *Output request form* for force analysis.

Opting to *exit* the *animation and trace* menu enables the return to the *kinematic output form* of Fig. 8b. Clicking now on *forces* causes the *force analysis* request menu (Fig. 10) to appear. At this point the user is offered a number of choices as to which external force unknown (torque T_1, or one of forces F_2, F_9, or P_1) he would like to determine. These options for the slider-crank mechanism are displayed in Fig. 10a, along with pin forces and reactions. It is to be pointed out that all pin forces and reactions shown in Fig. 10a are automatically computed, irrespective of the choice made by the user.
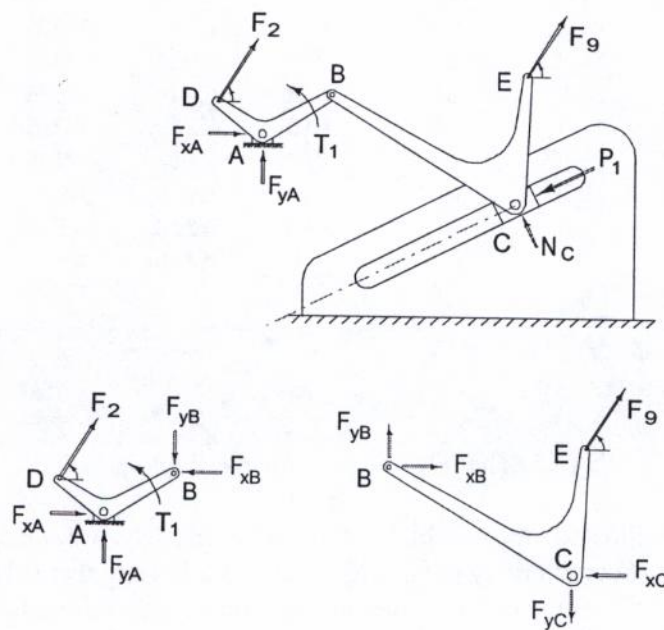

Fig. 10a. Output information for force analysis of the slider-crank mechanism.

Since it is desired to determine the allowable gas forces acting on the piston, *Piston Force* (P_1) is selected in Fig. 10. Selection of P_1 causes the message *Con. no #0 Slider* to appear on the window of this form, meaning that the current mechanism is the driving mechanism (of a possible chain), with no other mechanisms connected to it at this stage.

Al-Yaseer now presents, after a brief interval, the *Output Data* menu for forces (Fig. 11). This form provides a comprehensive set of output data comprising the results of dynamic analyses. All tractions shown in Fig. 10a are tabulated at one-degree intervals of the input crank. For identification of connected mechanisms, the *mechanism number* is displayed at the top of the form. The output data for dynamic analysis is also readily relayed to *Excel* for further processing. Thus it may be demonstrated that pin forces at the crank shaft at A (see Fig. 1), the pin at B, and the kingpin at C all feature a resonance-type peak at both the 90 deg and 270 deg positions of the crank, corresponding to the toggle positions. A similar trend at both crank locations is displayed in Fig. 12, where gas forces (*P. Force*) that are compatible with the input torque are plotted versus the crank displacement (*Theta2*).
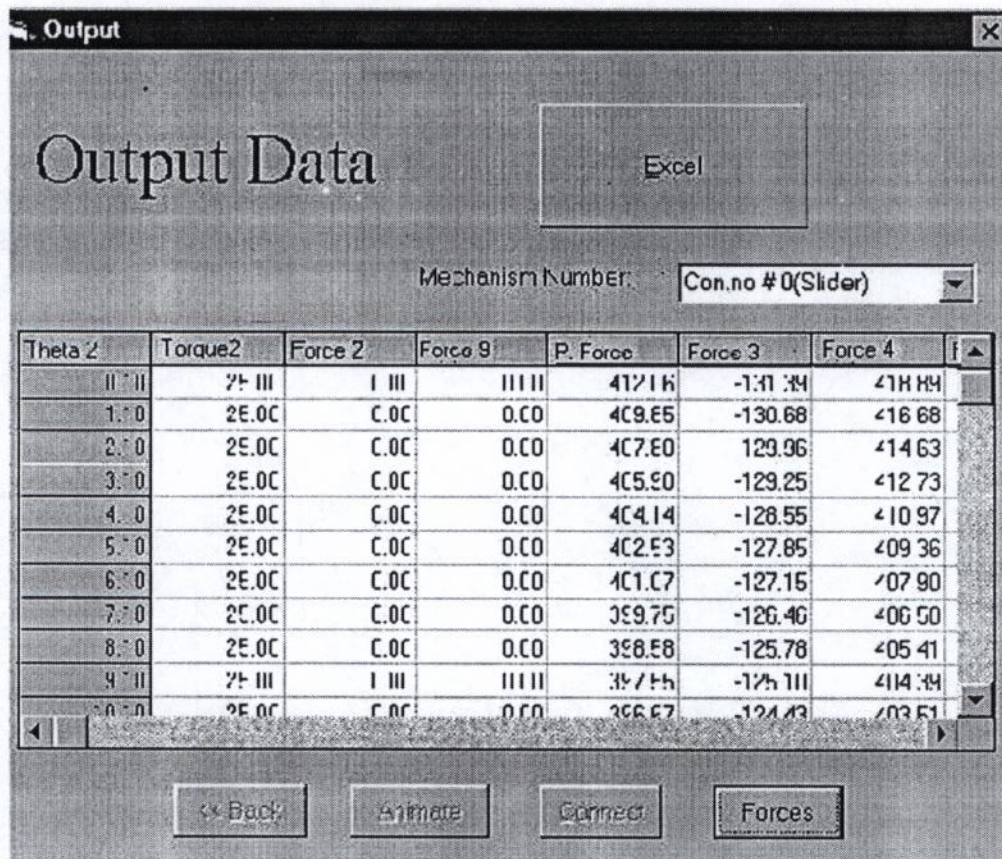

Output Data

Excel

Mechanism Number: Con.no # 0(Slider)

Theta 2	Torque2	Force 2	Force 9	P. Force	Force 3	Force 4
0.0	25.00	0.00	0.00	412.16	-131.39	218.89
1.0	25.00	0.00	0.00	409.85	-130.68	216.68
2.0	25.00	0.00	0.00	407.50	129.96	214.63
3.0	25.00	0.00	0.00	405.90	-129.25	212.73
4.0	25.00	0.00	0.00	404.14	-128.55	210.97
5.0	25.00	0.00	0.00	402.53	-127.85	209.36
6.0	25.00	0.00	0.00	401.07	-127.15	207.90
7.0	25.00	0.00	0.00	399.75	-126.46	206.50
8.0	25.00	0.00	0.00	398.58	-125.78	205.41
9.0	25.00	0.00	0.00	397.55	-125.11	204.39
10.0	25.00	0.00	0.00	396.67	-124.43	203.51

<< Back | Animate | Connect | Forces

Fig. 11. The *Output form for force analysis.*

In an effort to briefly illustrate the capability of *Al-Yaseer* in analyzing *combined linkages*, a ten-bar mechanism is considered briefly next. Fig. 13 shows a linkage that is being considered as a candidate to replace an existing disk cam mechanism with a reciprocating follower. Link BC is to be the input crank, and slider K, being the output member, would represent the reciprocating follower. Assuming that a uniform input speed is given, and all dimensions are known, the procedure of analysis would be as follows. Note that crank BC is on FISC mechanism ABCD. Thus one would first solve for the kinematics of the FISC mechanism, followed by the four-bar

linkage ADEF, where the input information for crank AD would be the same as the output link AD of the FISC. The kinematics of point G would be thus resolved. Defining next a *virtual crank* [3,4] AG, one would analyze the four-bar AGHJ. The output member HJ of the latter four-bar linkage would be the input crank of slider-crank mechanism JHK, whence the kinematics of slider K would be obtained.
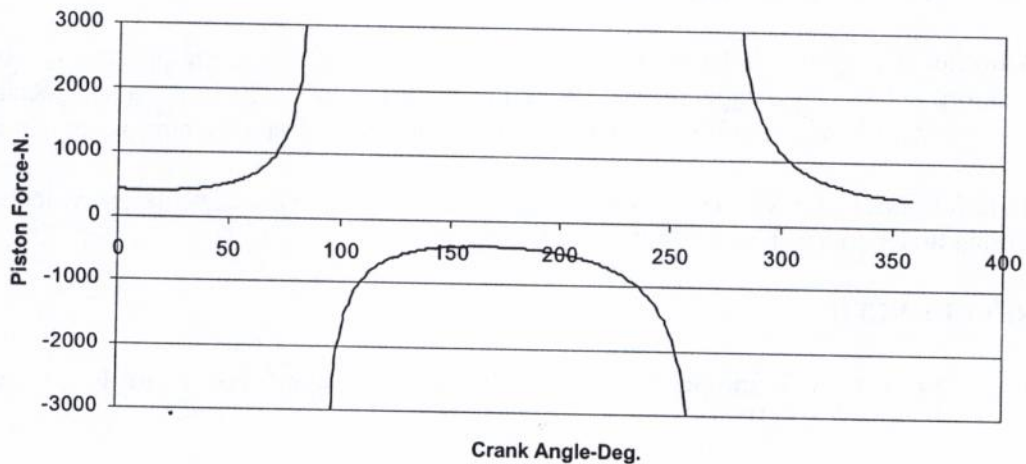

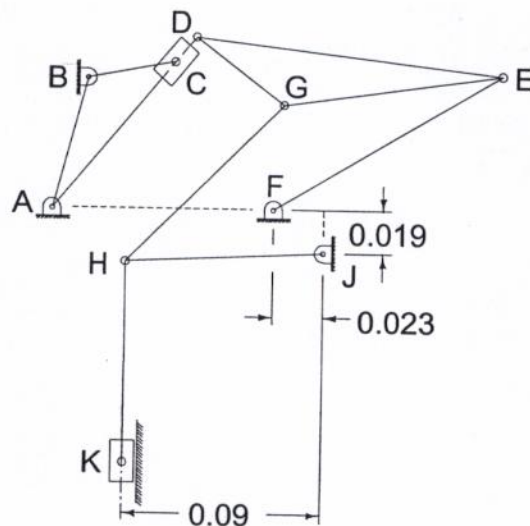Fig. 12. Variation of allowable piston force with crank displacement.

Fig. 13. Linkage-driven cam mechanism.

3.   CONCLUDING REMARKS

One of the outstanding features of *Al-Yaseer* is its connectivity. Although space restrictions do not permit the detailed demonstration of this powerful feature here, up to *ten interconnected basic planar mechanisms* can be analyzed both for kinematics and for determining forces and reaction forces. Animation of these mechanisms, and obtaining of traces of selected points are accomplished with little effort.

A significant advantage of *Al-Yaseer* is the fact that it provides the user with a comprehensive set of information on the kinematics as well as the dynamics of not only the members of a simple or combined mechanism, but also of specified points on the mechanisms. Thus the user has access to exhaustive information on all ground reactions as well as on joint forces and on other required force, torque and kinematic unknowns throughout the cycle of operation of the machine. All information becomes available after a *single* run. Kinematic and dynamic output data is readily transferred to Excel for further processing.

A further strength of *Al-Yaseer* emanates from the fact that the entire package can be run on desktop and laptop computers in a Windows environment. The expensive, specialized and stationary equipment that is prerequisite to other machine analysis programs is not required here.

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