



" PERSONAL COMPUTERS IN TEACHING DYNAMICS AND MECHANISM ANIMATION "

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INTRODUCTION :

Teaching the subject of kinematics and dynamics of machines calls for a good number of models and laboratory experiments in order to enable students to perform parametric studies of mechanisms. Conventionally, the lecturer has to bring heavy and robust mechanical models into the classroom or to design model linkage made from perspex in order to visualize mechanism motion using an overhead projector. The use of computer graphics supplemented with animation capabilities has certain advantages over conventional lecture and laboratory sessions. In addition, the use of such facility familiarize the student with the future role of design engineer with the computer loop. It facilitates design of mechanisms to accomplish certain prescribed functions by performing its kinematic and dynamic analysis.

Personal computers are seen as perfect tools for the development of such programs due to their modest cost and portability. In the present work, a number of programs developed on IBM/PC using BASIC are described. These programs include the dynamics of particles and rigid bodies in two dimensions and the kinematic diagrams of plane mechanisms.

PROGRAM EXAMPLES:

PLANE MOTION OF PARTICLES AND RIGID BODIES

1. MOTION OF A PARTICLE IN A GRAVITATIONAL FIELD

This program; ORBIT illustrates the motion of a particle moving in a plane under a central force of attraction such as a satellite in the earth's gravitational field. The problem is to calculate the orbits of such a satellite around the earth in free flight, when it starts its motion at an altitude of  $H_0$  above the surface of the earth and with an initial velocity of  $V_0$  directed radially outwards with respect to earth centre and the satellite engine is turned off. The particle then starts its plane motion. According to the gravitational law (Newton's law of gravity), the attraction force is inversely proportional to the square of the distance ( $d$ ) of the satellite from the centre of the earth. From Newton's law of motion the position  $x$ , velocity  $v$  and acceleration  $a$  are given by the following vector quantities:

$$\begin{aligned} dx/dt &= v && \dots\dots(1) \\ dv/dt &= a && \dots\dots(2) \\ a &= -K/d^2 && \dots\dots(3) \end{aligned}$$

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Where  $K$  is a constant which can be easily calculated since  $a=9.81$  m/sec at the surface of the earth.

Solution of these equations in time domain, is performed using an iterative method for predefined degree of accuracy using the point integration method. The time domain is discretized into equal intervals as dictated by the user. This time increment can be changed to assess the accuracy of the solution. The values of the radius of the earth  $R$ , its mass  $M$ , the mass of the satellite  $m$ , and the gravitational constant  $K$  are prescribed in the program as input data. The program asks the user to supply initial values of altitude and velocity  $H_0$  and  $V_0$  respectively. The path is then calculated by applying the midpoint rule to get the new position of the satellite after the predetermined time interval  $DT$  from the following equations:

$$X = X + V_X * DT \quad \dots\dots(4)$$

$$Y = Y + V_Y * DT \quad \dots\dots(5)$$

Where  $V_X$  and  $V_Y$  are the velocity components as shown in Fig. (1.a).

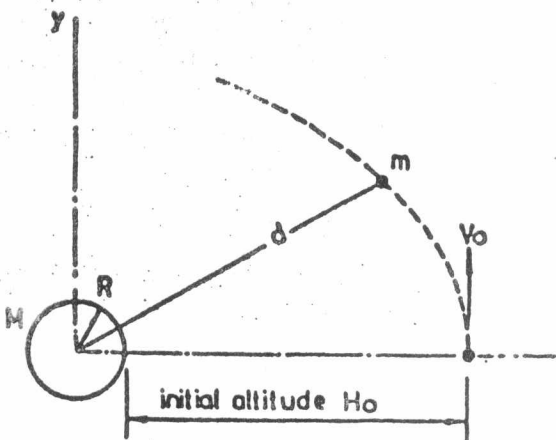


Fig. 1a

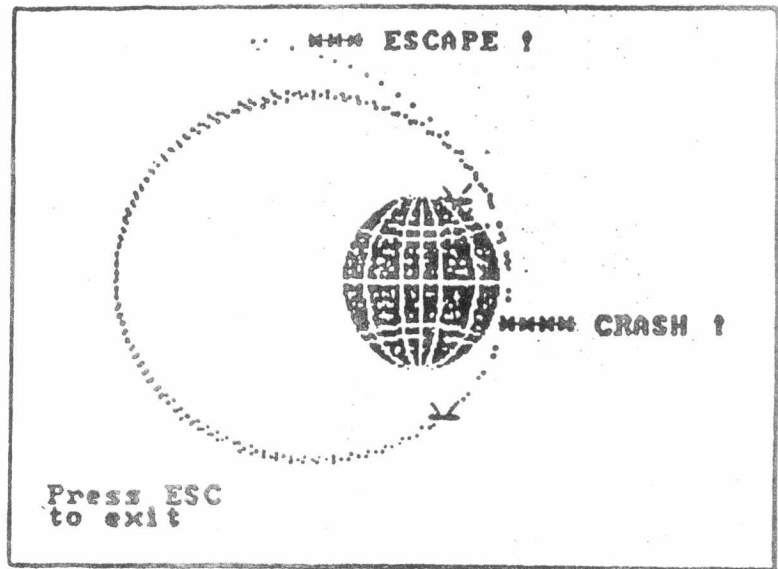


Fig. 1b

The new distance ( $d$ ) is calculated by Pythagorean theorem and is then used to calculate the new values of the components of the acceleration at the new time. As solution proceeds, the program animates the satellite motion, traces its orbit and continually displays the values of the current altitude, velocity and time elapsed on the screen. Depending on the initial conditions ( $H_0, V_0$ ), the satellite may go into stable orbit around the earth, escape orbit or crash to the surface of the earth. All such possibilities are declared by the program during its animation path as shown in Fig. (1.b).

The program can be further developed to take into account the effect of other gravitational fields on the satellite motion.

## 2. UNRESISTED MOTION OF PROJECTILES

This program ;PROJECTILES ; illustrates the unresisted motion of a particle under gravitational force such as the projectile of a cannon hitting a prescribed target. As shown in Fig. (2.a), a particle with initial position  $(X_0, Y_0)$  is projected with an initial velocity components  $u_0, v_0$  in order to hit a target at the point  $X_t, Y_t$ . The parabolic equation of the path can be easily derived by time integration of Newton's law equation of motion:

$$d^2x/dt^2=0 \quad \dots\dots(2.1)$$

$$d^2y/dt^2=-g \quad \dots\dots(2.2)$$

The program is fed with the cannon altitude  $Y_0$ , the target position  $X_t, Y_t$  by the user. The initial velocity  $V_0$  is predetermined and may vary according to the kind of cannon used.

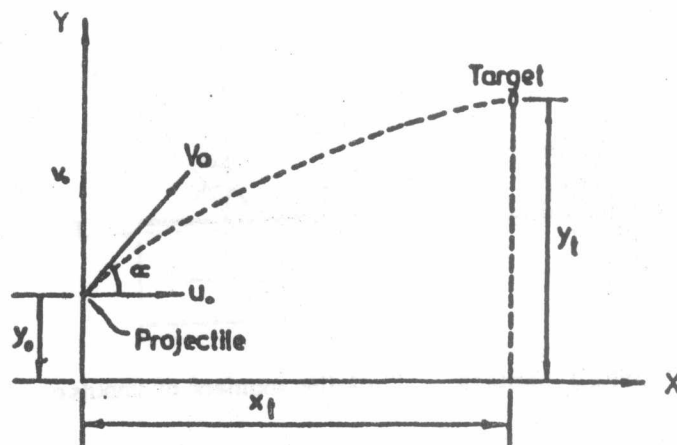


Fig. 2a

The program solves the parabolic path equation to calculate the angle of inclination  $(\alpha)$  required to satisfy the condition of the bullet hitting the prescribed target point. The motion of the projectile is animated on the screen as shown in Fig.(2.b). After hitting a target the program will ask the user to specify another target position and cannon altitude and the process is repeated.

This program illustrates very clearly, for the students studying mechanics, the parameters that affect motion of projectiles under gravity effect. The program can be further developed to take into consideration both the resistance of air and change of gravitational constant on the projectile path.

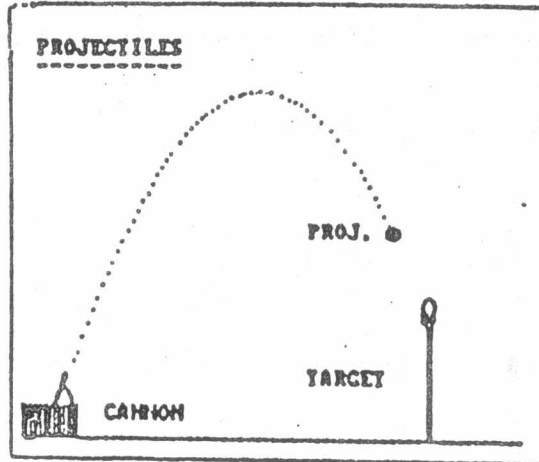


Fig. 2.b

### 3. IMPULSE OF RIGID BODIES

This program ;IMPULSE illustrates the plane motion of a rigid body which falls freely from a prescribed altitude before it is struck by a knife edged support. A rigid bar (L-shaped for clarity) with mass  $m$  at point  $G$  and radius of gyration  $k$  is considered as shown in Fig.(3.a).

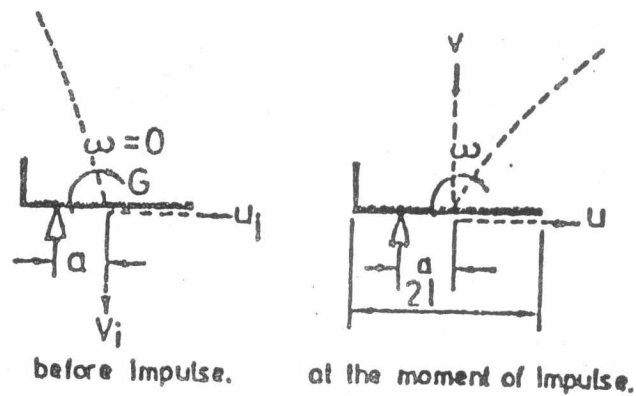


Fig. 3.a

Applying the principles of linear and angular momentum to determine the time-integral of  $F_x, F_y$  and  $M$ ; the forces and moments acting on the body over the short duration of the impulse yields:

$$m (u - u_i) = F_x \quad \dots\dots(3.1)$$

$$m (v - v_i) = F_y \quad \dots\dots(3.2)$$

$$mk (w - w_i) = M \quad \dots\dots(3.3)$$

Where  $u, v$  and  $w$  are the velocity components and angular velocity just after the impulse and  $u_i, v_i$  and  $w_i$  are respectively the values just before

the impulse. Equations (3.1) to (3.3) are used together with the value of the coefficient of restitution to determine  $u$ ,  $v$  and  $w$  subsequently, the equation of motion is solved to determine the path the body after the impulse.

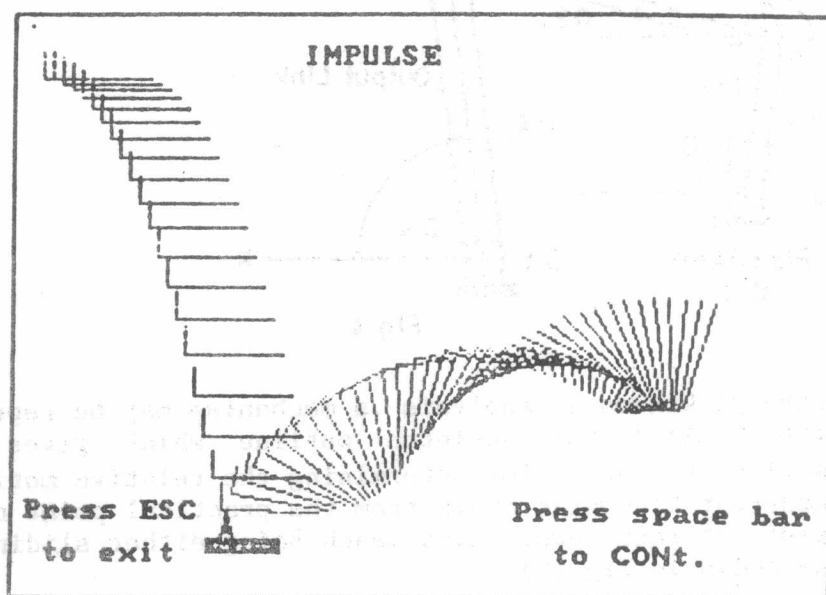


Fig. 3.b

The program data are the bar mass  $m$ , its radius of gyration  $k$ , the coefficient of restitution. The user controls the position of the knife edge using the space bar. The program animates the body and traces the path of the point  $G$  during its free falling and the subsequent motion after the impulse as shown in Fig.(3.b).

### ANIMATION OF PLANE MECHANISMS

Teaching the subject of dynamics of machines calls for a good deal of models and experiments. Moreover, certain topics in kinematics can be very hard to explain without the ability to display its motion. Therefore, a family of programs are developed for the purpose of animating mechanism motion.

The familiar four bar chain mechanism which consists of four turning pairs is shown in Fig (4). The links have the lengths  $R1$  for the fixed link,  $R2$  for the driving link,  $R3$  for the coupler link and  $R4$  for the driven link. Since the four-bar chain has one degree of freedom, then prescribing the angle  $Q2$  of the driving link will completely specify the position of the rest of the mechanism, (discounting the branching possibility).

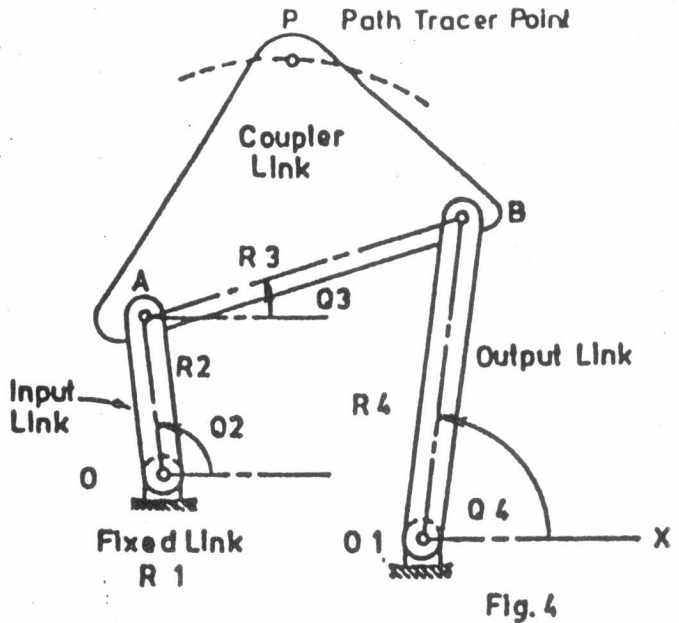


Fig. 4

For the purpose of kinematic analysis ,a mechanism may be represented in an abbreviated form called the skeleton outline which gives all the geometrical informations necessary for determining the relative motions of its links. The most important kinematic chain from the practical point of view are those which consist of four lower pairs ,each being either sliding [S] or turning pair [T] as shown in Fig.(5).

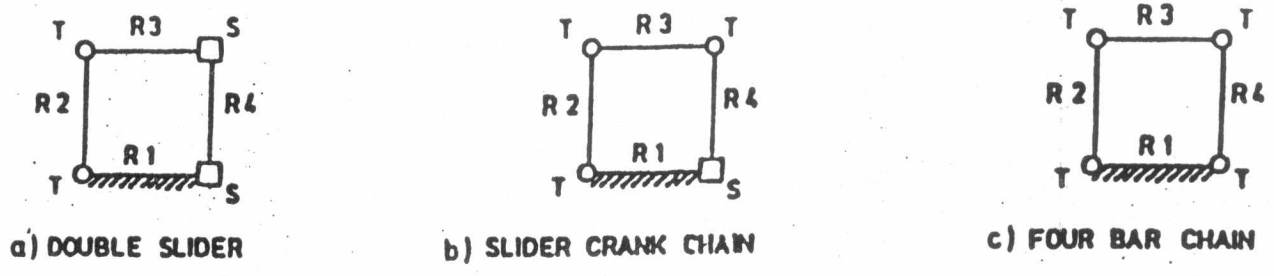


Fig. 5

Various inversions of the mechanism depend solely on the relative lengths of the links and the prescribed linkage configuration also ,the same linkage can be of different type, depending on which link is specified as the fixed (or ground) one.

1) FOUR-BAR CHAIN MECHANISM:

This interactive program ;FBCM illustrates the kinematics of a simple four-bar chain mechanism with four turning pairs. Referring to Fig.(6.a,b) ,the independent parameter is the angle Q2 of the driving link R2 with respect to the fixed x axis. The lengths of the links R1 ,R2 ,R3 and R4 plus the two distances F and G of the tracing point P on the coupler link are the input data for the mechanism in a selected configuration.

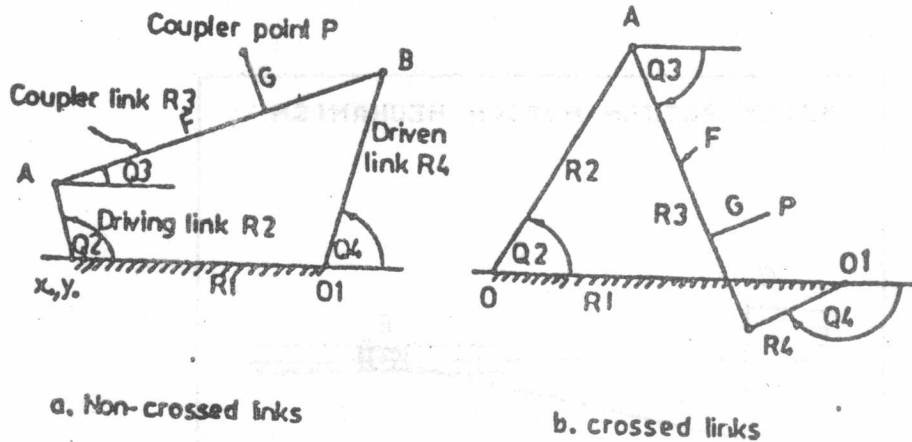


Fig.6 Four-bar mechanism.

The generated mechanism may take the form of a so called CRANK-ROCKER or a DOUBLE-ROCKER or a DOUBLE-CRANK linkage depending on the range of motion of the two links connected to the ground link. The mechanism is classified according to Grashoff's criterion. Analytical expressions are available for the absolute angular positions of the links of the four-bar linkage which are easily programmed to calculate the unknown dependent parameters Q3 and Q4. The program animates the four-bar chain mechanism and displays the coupler curve of point P on the coupler link ,as shown in Fig.(7).

It is intended to develop the program to calculate and plot the velocities and accelerations of different links which will be of great value in studying dynamics of the mechanism.

**FOUR-BAR CHAIN MECHANISM**

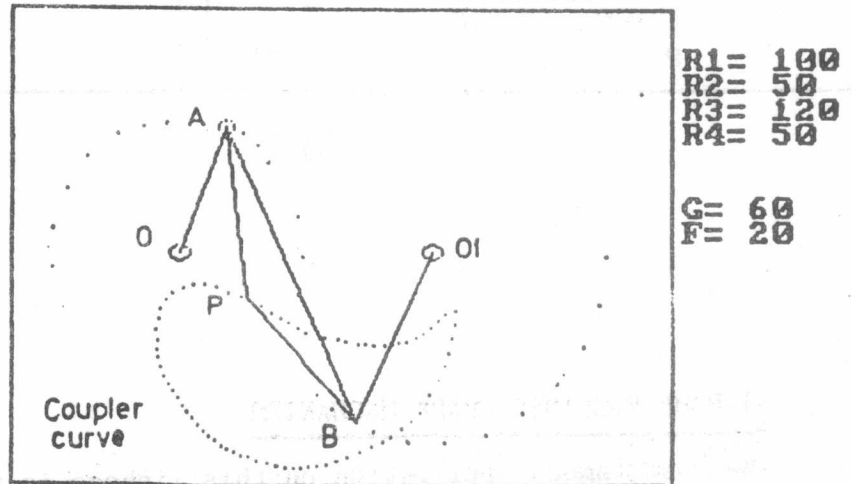


Fig.7

**2) SLIDER-CRANK MECHANISM**

This four-bar chain Fig.(8) ,consists of three turning pairs and one sliding pair. The geometry of the mechanism turns to a simple crank mechanism when the offset value E is set to zero. An elliptical and straight line

coupler curves can be generated by proper selection of relative crank to connecting rod lengths and the location of the point P on the coupler link as shown in Fig.(9.a,b).

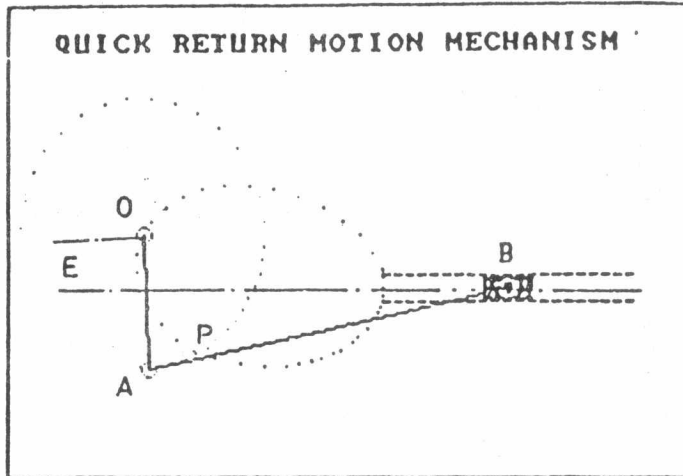


Fig. 8

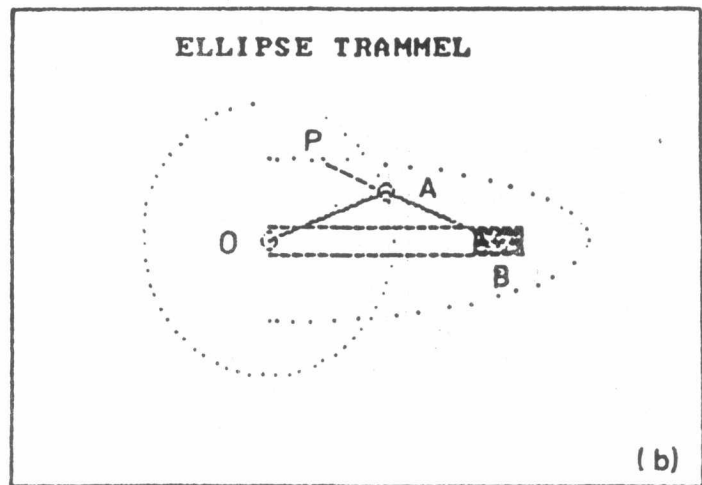
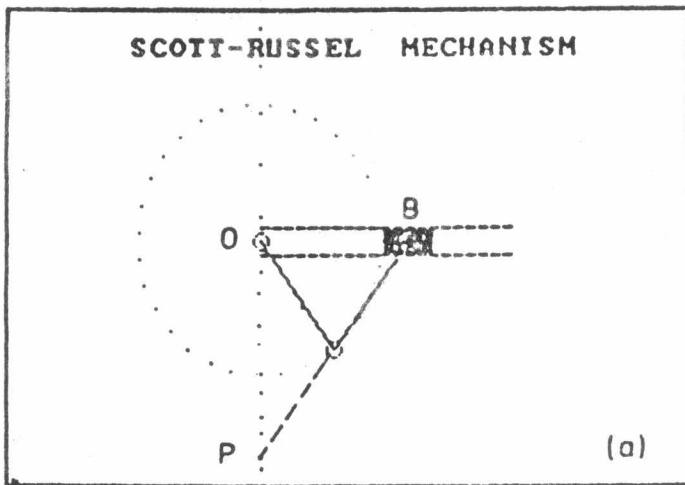


Fig. 9

### 3) DOUBLE-SLIDER CRANK MECHANISM

The most famous application on this linkage is the scotch-yoke mechanism. This interactive program animates this simple four-bar chain with two sliding and two turning pairs which is used to convert rotary into reciprocating motion. The program allows the user to study the motion of the mechanism, change its dimensions and animates the mechanism as shown in Fig. (10).



A program list is given in appendix together with sufficient comments to explain the animation steps.

### THE SCOTCH YOKE MECHANISM.

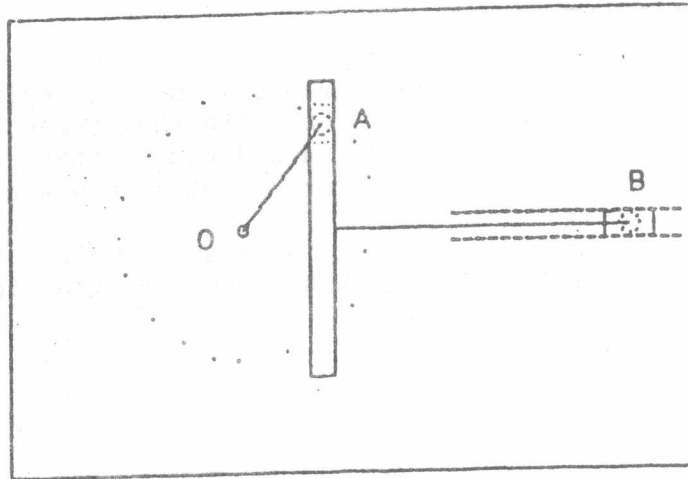
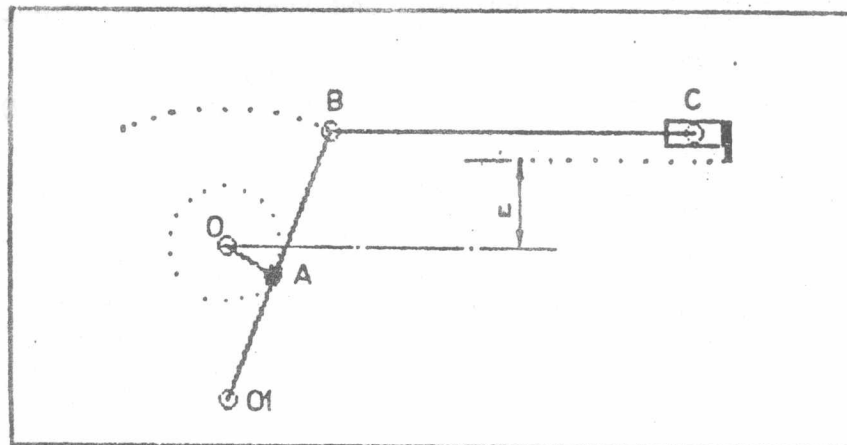


Fig. 10

### 4) SHAPING MACHINE MECHANISM

This mechanism which is known as Whitworth quick-return motion, used in shaping machines is an inversion of the slider-crank chain. It is obtained by fixing the link R2 as illustrated in Fig.(11).

### WHITWORTH QUICK-RETURN MOTION



Press ESC  
to exit

Press space bar  
to cont.

Fig.11

The program is an application illustrating how to obtain a complicated



mechanism by the combining different inversions of a simple chain and also how to get another mechanism configuration by changing the relative linkage dimensions.

\* Limitations and applications:

The main function of the above programs is not to replace the instructor, but to enable the instructor to interact with the students in a better way in order to visualize easily the motion in a dynamic sense. They were found to increase student/instructor interaction and to stimulate student interest.

These programs ,written in compiled Microsoft BASIC run under PC DOS 2.0, and require a minimum of 48K RAM. A hard copy of graphics can be obtained on Epson MX-100.

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