This paper describes a generalized program for the analysis and design of plate cam and follower mechanisms using a graphic display console. The experimental program was developed to study the use of interactive graphics systems for solving mechanical design problems.

The program can handle almost all types of plate cam and follower mechanisms. A wide selection of motion curves permits the designer to specify any desired motion of a point of interest by synthesizing several curves into a displacement diagram.

INTERACTIVE GRAPHICS IN DATA PROCESSING

Cam design on a graphics console

by J. M. Lafuente

Graphic display devices can combine the power and speed of a digital computer with the creativity of the designer and engineer. Because mechanical design is a highly iterative process, the man-machine interaction made possible by graphic display devices is particularly useful in this case.

The experimental graphics cam design program described in this paper was developed to study the application of graphic display devices to mechanical design problems and to explore programming techniques for communicating graphically with a computer while solving such problems. The program was originally written for the IBM 7090 computer as part of a COMputer-aided Mechanical ENgineering Design system (COMMEND).[1,2] The cam design procedure used in the program is based on the envelope theory, which is described in References 3 through 6.

Graphics in mechanical design

The use of computers to solve engineering design problems has been limited by the lack of effective man-machine communication and the burden of programming, which requires the user to learn a programming language in order to instruct the computer to solve his problems.

design procedure

The steps normally taken in using the computer to solve a mechanical design problem are:

1. Develop a program.
2. Transcribe design data into a suitable format on a computer input medium, usually punched cards.
3. Execute the program to obtain the computer-controlled solution of the problem.
4. Obtain output, usually in printed tabular form, and interpret results.
5. Alter input data.

Steps 2 through 5 are repeated until the design criteria are met.

Graphic display devices provide the ability to communicate with the computer in a natural way, without translation of the design data, and thus establish a meaningful man-machine interaction. A graphic display device connected on-line to a computer offers a medium by which the designer can enter design data in graphic form and cause the computer to display results on the graphics console screen. This is a decision point at which the designer at the console intervenes. The designer can make changes by means of a light pen and other manual input features and redisplay the results.

The graphic mode of operation permits more design iterations per unit time. The benefits are reduced product development time, as a result of eliminating objectionable turnaround times, and better product quality, because of the additional design and analysis cycles.

Traditionally it has been necessary to develop complex programs that handle every possible situation. Now the design criteria can be specified at the graphics console, and the operator is asked for advice whenever errors or unusual conditions exist. The net result is that the machine alone no longer controls the flow of the program; the creativity of the designer has been incorporated into the system. This is of specific value to mechanical engineering design where the many variables may make mathematical solutions impractical. In many instances, the graphics approach makes it possible for the mechanical engineer to save a significant amount of design time by selecting and assembling the various elements of solution on the display screen.

Recent advancements in computer technology are increasing the potential of computer graphics in mechanical engineering design.

Graphics cam design program

In cam[7] design problems, certain prescribed conditions must be fulfilled for a design to be acceptable, and more than one solution usually satisfies the requirements of a particular application. A straightforward procedure may not be available, and an optimum design is only obtained after many trials, each with slightly different input data. In a computation center, this is a costly and time-consuming operation. The graphics cam design program seeks to improve this situation by providing a fast man-machine interaction, whereby the designer may change the design, have the results displayed on the display screen, and manipulate the input parameters in various combinations until an acceptable cam-follower mechanism is obtained.

By showing the results in graphic form, the operator can quickly examine the overall characteristics of the resultant system and take immediate action. Errors are easily detected, and time loss because of erroneous data is effectively minimized. Program checks and warning messages are available to guide the operator during the design operation and to indicate invalid conditions.

A high degree of flexibility is provided, since the program can handle almost every possible type of plate cam and associated follower mechanism. A wide selection of motion curves permits the designer to specify any desired motion of a point of interest by synthesizing several curves into a displacement diagram.

Printed results may be delayed until the final design is obtained. The output may be directed to an x-y plotter or may be recorded on microfilm.

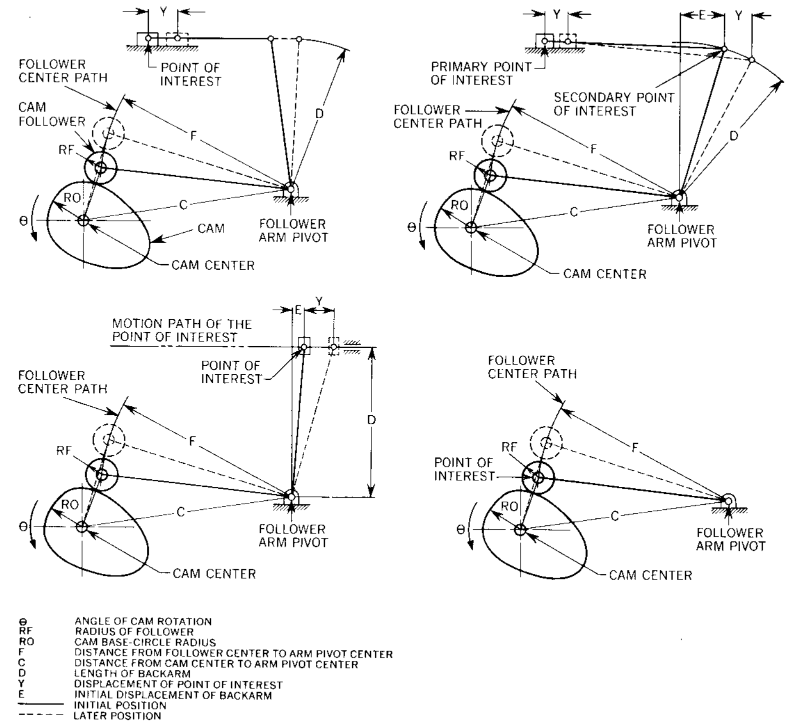
program operation

The cam design program presents five display formats, or *panels,* to the user. The five are called the cam design, linkage, dimensions, motion, and calculations panels.

The cam design panel is displayed first and redisplayed at appropriate times during the problem solution. Depending on his progress in solving the problem, the designer uses the cam design panel to request any of three functions. He can select the section of input data to be described initially and subsequently modified (by selecting the word LINKAGE, DIMENSIONS, or MOTION); he can select the computation program that computes and displays the results on the screen (by selecting the word CALCULATIONS); or he can request the results in final printed form (by selecting HARD-COPY OUTPUT). Neither CALCULATIONS nor HARD-COPY OUTPUT can be selected until all input parameters have been specified. Selecting CALCULATIONS on the cam design panel causes display of the calculations panel, which, in turn, shows the results of the computations on the screen.

The linkage panel enables the designer to describe the type of cam-follower mechanism desired. He specifies linkage characteristics by proper selection in subsequent subpanels that display the type of follower arm, the follower type, and the follower linkage type. Either of two types of follower arms can be selected: the pivoting type, in which the follower arm pivots about a fixed point, or the translating type, in which the follower arm is constrained to move in a straight line. Also, either of two types of followers can be selected: the roller type, which can be represented by a circle, and the flat-face type, which can be represented by a straight line. Four basic types of follower linkages are provided, as shown in Figure 1.

Figure 1 Follower linkages

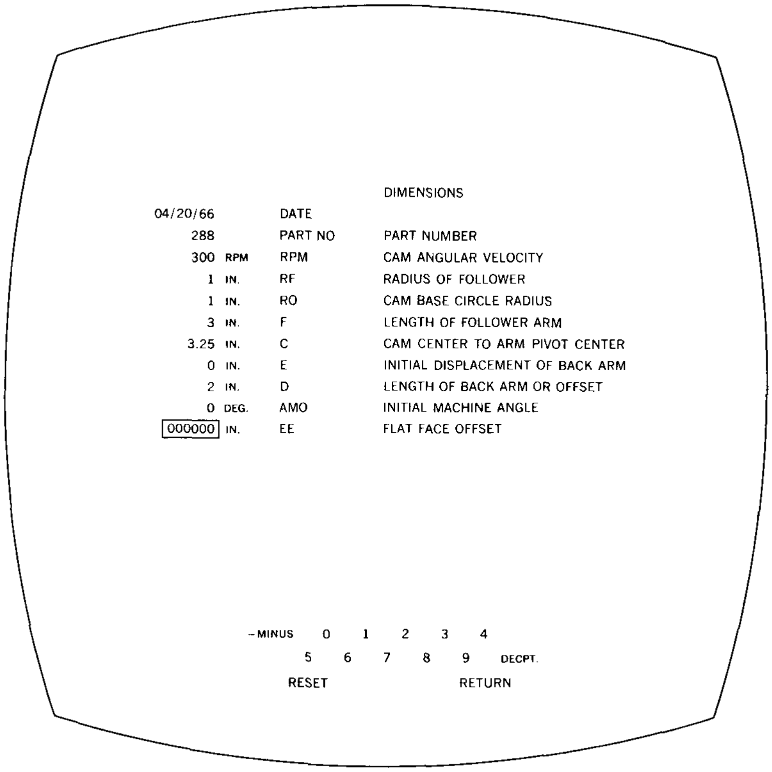


The dimensions panel is used by the designer to specify the parameters of the input data pertaining to the physical characteristics of the cam-follower mechanism. Selecting any of the dimensions panel options shown in Figure 2 clears the corresponding storage location in the computer and causes a box to be displayed on the screen. Digits from the table of numbers on the lower part of the display may then be entered into the box with the light pen. Two additional options, RESET and RETURN, may be used to restart the dimensions panel or go back to the initial cam design panel.

The motion panel, illustrated in Figure 3, is used by the designer to describe the desired motion of the point of interest. The designer can specify the duration angle, displacement, and curve type for each section using a technique similar to that used in the dimensions panel. As he proceeds from section to section, the motion diagram is automatically generated on the display screen. It is possible to refer to any curve for a particular section at any time, in order to change parameters or to display any curve for a particular section without proceeding further. The program checks the validity of the input data and asks for additional parameters to be supplied whenever one of the special types of polynomial curves is requested.

The program contains the mathematical equations for twenty-eight types of motion curves, some of them having variable shape.

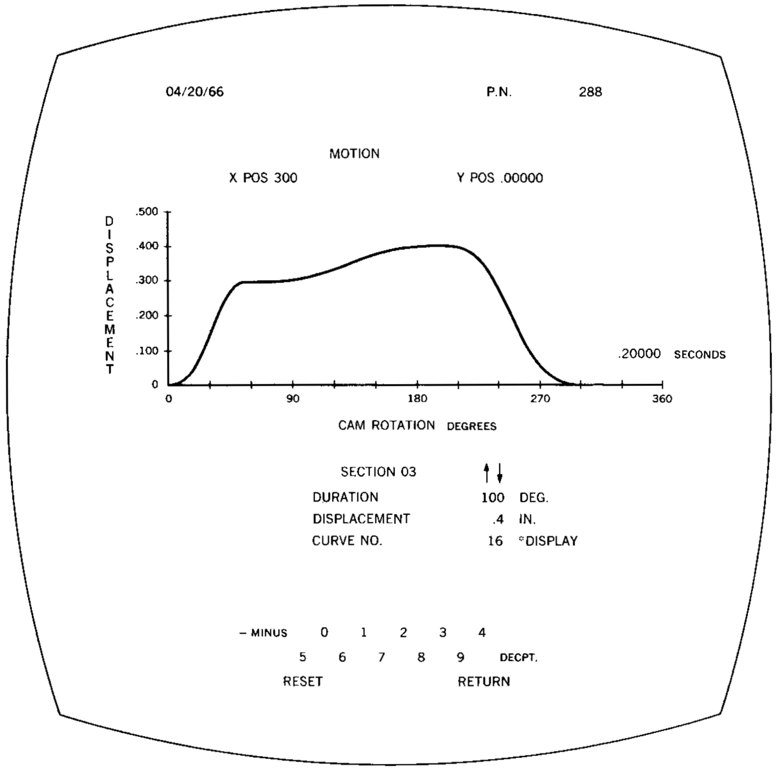
Figure 2 Dimensions panel



This selection provides a degree of flexibility in synthesizing the displacement diagram. A list of the available curves can be obtained by pressing a function key to the left of the graphic display unit. From this list, a curve can be selected with the light pen or by specifying a two-digit code number. Several motion curves can be combined to form the displacement diagram of the point of interest and satisfy the desired motion requirements and the continuity of displacement, velocity, and acceleration. The motion diagram is completed when the designer specifies 360 degrees of cam rotation. Just as in the dimensions panel, the RESET and RETURN options are provided to redefine the motion diagram and to return to the cam design panel, respectively.

The calculations panel, which is displayed during the design computations, shows the displacement, velocity, and acceleration curves for the point of interest being plotted as the program computes the results. The outline of the cam is also traced along with the output curves. The calculations panel is illustrated in Figure 4. Warning messages concerning certain design problems are displayed in this panel. For example, if the pressure angle at any time exceeds 40 degrees, the message PRESSURE ANGLE EXCEEDS MAXIMUM is displayed to signal the designer that a redesign may be necessary. If the radius of curvature of the follower path at any point is less than the radius of the follower, a warning message is

Figure 3 Motion panel



displayed to alert the user that the phenomenon of undercut is present.

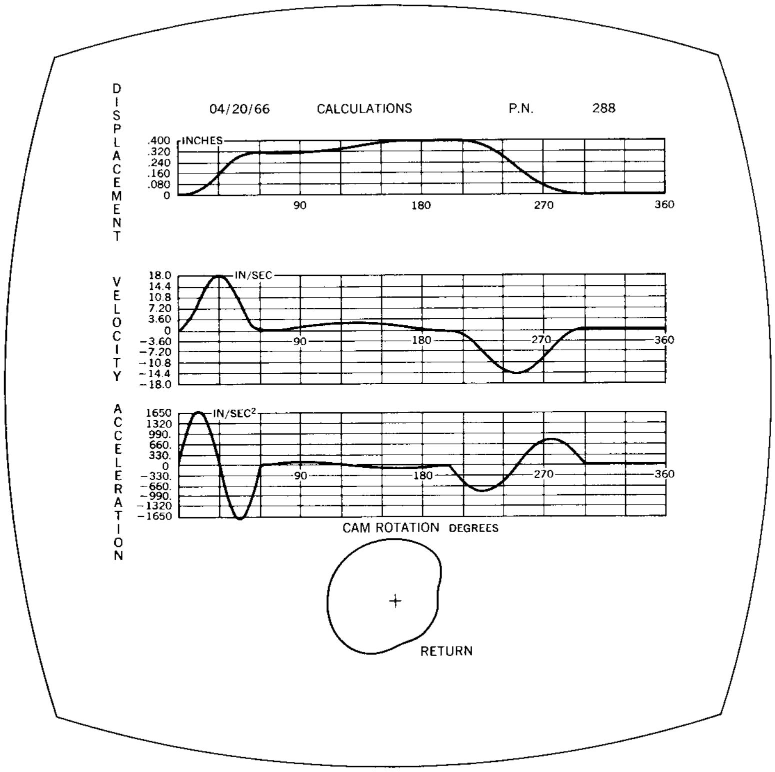
Selection of the RETURN option on the lower part of the display causes the initial cam design panel to be redisplayed. All input data is saved after completion of the design, and the operator can change any input parameters and repeat the calculations, or he can proceed to an entirely different problem. If a design is satisfactory, the designer may point to HARD-COPY OUTPUT after RETURN from the calculations panel.

Choosing the HARD-COPY OUTPUT option causes the design results to be printed on the system on-line printer. Output information consists of tables of displacement, velocity, and acceleration of the point of interest, pressure angle, and radius of curvature of the follower path at specified degree intervals over the cam profile. Manufacturing information is also available in a cutting schedule at specified intervals. Output may be directed to a plotting device or to a film recorder. It is possible to produce output on tape for a numerically controlled cutting machine by pressing a function key.

Summary comment

The experimental program described in this paper illustrates the feasibility of computer-aided mechanical design by means of inter-

Figure 4 Calculations panel



active graphic devices. The value of man-machine interaction in solving mechanical design problems is due to the fact that the design process usually involves repeated cycles of computation, analysis, and parameter variation. The most important advantages are reduced turnaround time, the ability to present graphic input to the computer, graphic presentation of the results, faster user response to errors, and increased program flexibility. In summary, the interactive graphics cam design program permits many program iterations in a small amount of time.

In our experience with the program, computer response to the console operator was found to be considerably faster than necessary. Except for the actual computation phase, the program requirements in terms of central processing unit time and main storage capacity were minimum. These facts suggest the desirability of computer-aided engineering design on time-sharing systems. The most suitable configuration seems to be a graphic display device attached to a small computer, but with the capacity and versatility to communicate quickly and efficiently with the operator, and the capability to communicate with a large computer to satisfy the intermittent need for increased computing power and greater storage capacity.

Whenever possible, a fixed-input mode of operation, with limited use of a display console, is desirable because it is more economical of computing system resources. For very complex problems, a conversational mode of operation is suggested.

ACKNOWLEDGMENT

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