Computer Based Instruction Module – Kinematics of Gears[1]

Edward E. Anderson

Department of Mechanical Engineering
Texas Tech University

Introduction

Today, very little of the application of theory to engineering practice is learned by "hands-on" laboratory experience. Rather, much of this type of learning is done by presentation, demonstration, modeling, and simulation. Factors, such as cost of developing experiments, operating, and maintaining laboratories, student time constraints, as well as modeling and simulation improvements, have all contributed to this trend. But, many engineering practices cannot be modeled or simulated, they can only be experienced.

Students often view modeling and simulation as theoretical, not "real world," efforts. This reduces the credibility of the models and simulations, which interferes with the learning process. Synchronization of the laboratory experience with the appropriate class material has always been and continues to be a problem. This also interferes with the learning process since the correlation of the theoretical and physical world is difficult to make. This interference can be reduced by repeating the theoretical development at the time of the experiment. But, this may not be an efficient use of the learning time.

In a recent speech, Michael Parmentier[7], Director of Readiness and Training, U.S. Office of the Secretary of Defense, referred to today's learners as "The Nintendo Generation" whose first choice for learning is not static text and graphics, but rather is interaction with rich multimedia and simulations. Consequently, the U.S. Department of Defense recently awarded major contracts for the Advanced Distributed Learning project whose goal is to develop systems and standards that better integrate the rather static world of today's web-based instruction materials with models and real-time simulations.

It is well known that students learn more as they become more engaged with the materials. Reiseman and Carr[8] have concluded that students learn 20% of the material taught by hearing, 40% by seeing and hearing, and 75% by seeing, hearing, and doing. Highly interactive, well-designed computer-based-instruction (CBI) modules, such as those reported by Anderson[2,3,4], then offer the possibility of achieving the 75% goal. Renshaw, et al.[9] state "students unanimously preferred modules that incorporated

[1] Supported in part by the National Science Foundation under CCLI grant 0089410

animations and interactive design tools." Aedo, et al.[1] [2000], Grimmoni, et al.[5], Holzer and Andruet[6], Sulzmann, et al.[10], and Hashemi, et al.[11] have reported similar findings in several engineering fields. Since students prefer interactive multimedia modules and retain more material presented in this way, the goal of any CBI module should be to use interactive engaging material rather than static material.

The challenge is then one of developing laboratory simulations that are simple, relate to the learner's experience level, and that can be incorporated into and synchronized with other teaching pedagogies. These also need to be structured so that learners can proceed at their pace, receive appropriate feedback and coaching, and can review as often as necessary to master the material. This paper presents and discusses one such simulation for the learning of gear kinematics and dynamics.

Gear Kinematics and Forces

The CBI example in this paper demonstrates the motion of gears, the concepts of contact points and lines of action and the forces, including friction forces, acting on gear teeth as they progress through one cycle of contact. Questions for the students to answer are posed throughout the presentation. Also, student conducted experiments are suggested throughout the presentation. These experiments are designed to assist the student with answering the questions raised and to visualize concepts that are difficult to visualize using static images and presentations. All experiments are conducted by observing a pair of gears in motion and then performing frame-to-frame analysis of the gear images.

The goal of the first animation is to familiarize the student with (a) gear nomenclature and (b) the animation operational controls. A sample frame of the first animation in the presentation is shown in Figure 1. This particular experiment involves a pair of 20^{o}, 10 pitch gears with different pitch diameters. The gear on the right is the driver gear while that on the left is the driven gear. Only enough of each gear is shown to focus the student's attention upon the contact between two of the gear teeth. The respective pitch circles and contact line of action are also shown in this typical frame of the animation.

Animation controls appear as buttons across the bottom of the animations. With these controls, the student can: (Next) proceed to the next animation, (Frame) determine which frame is being displayed, (Stop) stop the animation, (Play) play the animation, (Advance) advance to the next animation frame, and (Reverse) back up to the proceeding frame of the animation. The animation is playing when it is first presented. Students use these controls to stop the playing animation, to view selected frames and to proceed to the next animation or screen.

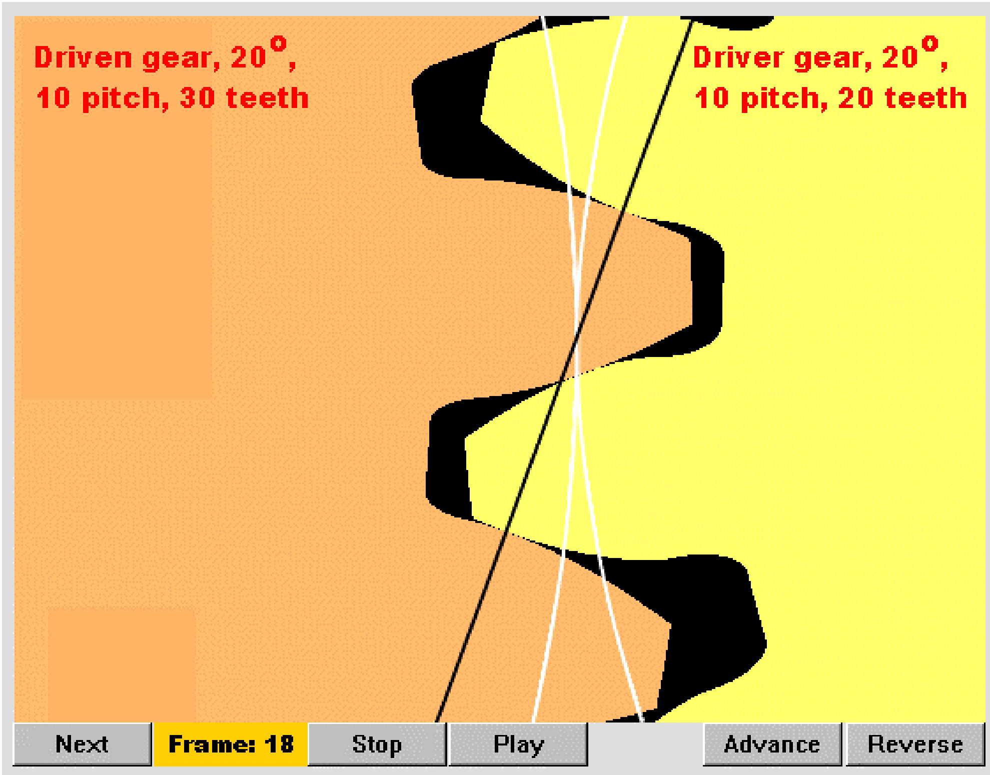

Fig. 1 - Typical Gear Nomenclature Frame of the First Animation

The objective of the second gear animation is to teach the students about the points of contact between the two gears. The animation demonstrates that during the first part of the contact cycle there are two points of contact and during the second part of the cycle there is only one point of contact. The lesson starts with a screen explaining that the animation will display the point(s) of contact during the cycle and that the student should focus upon the number of points of contact and the amount of time the various point(s) of contact appear.

The second animation is then played while the question to be answered is displayed. The final frame of this animation is presented in Figure 2. This frame displays two points of contact. After stopping the animation, students use the Advance and Reverse button with the Frames counter to determine when the contact cycle begins, when it ends, and the frame at which there is a transition from two points of contact to a single point of contact. These frame counts can then be used to determine the fraction of the cycle during which there are two points of contact as well as when there is a single point of contact. This exercise clearly demonstrates the transition of contact from two pairs of gear teeth to a single pair of gear teeth.

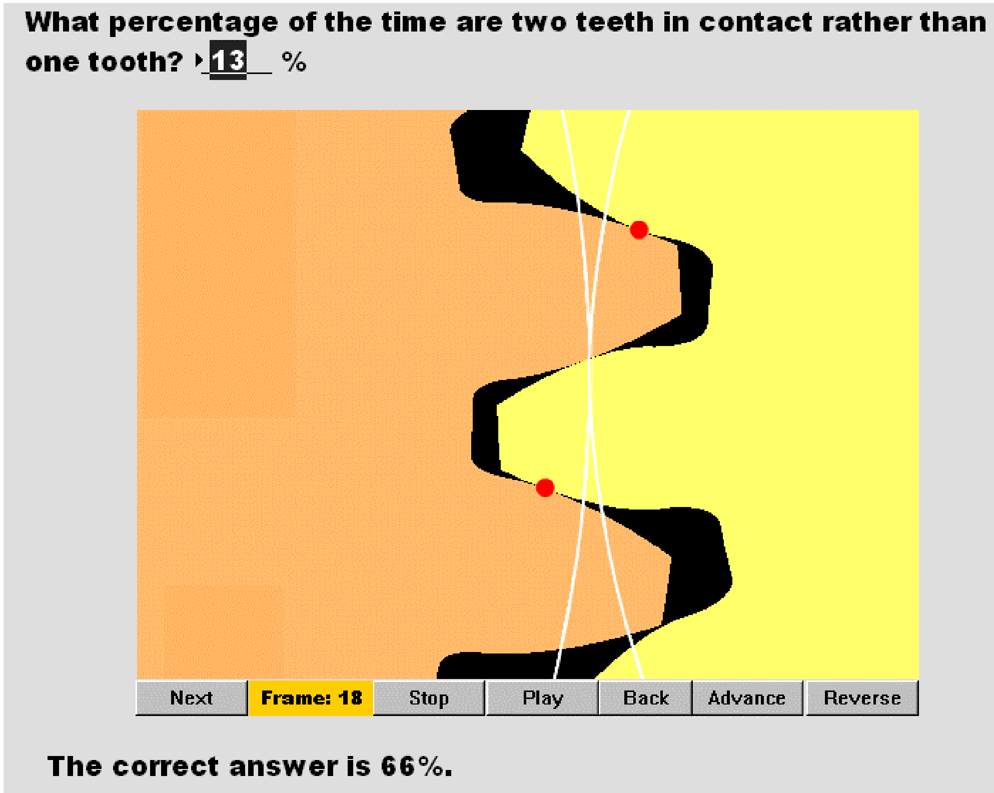

Fig. 2 - Final Frame of the
Second Animation Demonstrating the Gear Contact Points

The third animation familiarizes the student with the line of contact and the pressure angle of the gear set. Figure 3 displays a screen near the middle of this animation that traces the line of contact formed by the points of contact during one cycle of contact. The initial contact point is shown as a solid circle, the final contact point as an open circle, and the line of contact as a solid line. During the third animation , the student follows the points of contact as it moves along the line of contact.

In order to keep the students actively engaged with the material being presented, they are asked to determine the pressure angle from the information presented during the third animation. This was presented in the initial screen as 20^{o}. It is asked again in order to (a) reinforce the earlier information and (b) relate this earlier information to the kinematics of the gear motion. Students can readily answer this question by recalling the information during the initial animation, measuring the angle on the screen with a protractor, or by eye-ball estimation. Once the question is answered, the student is informed about the accuracy of the answer and coached about the correct answer.

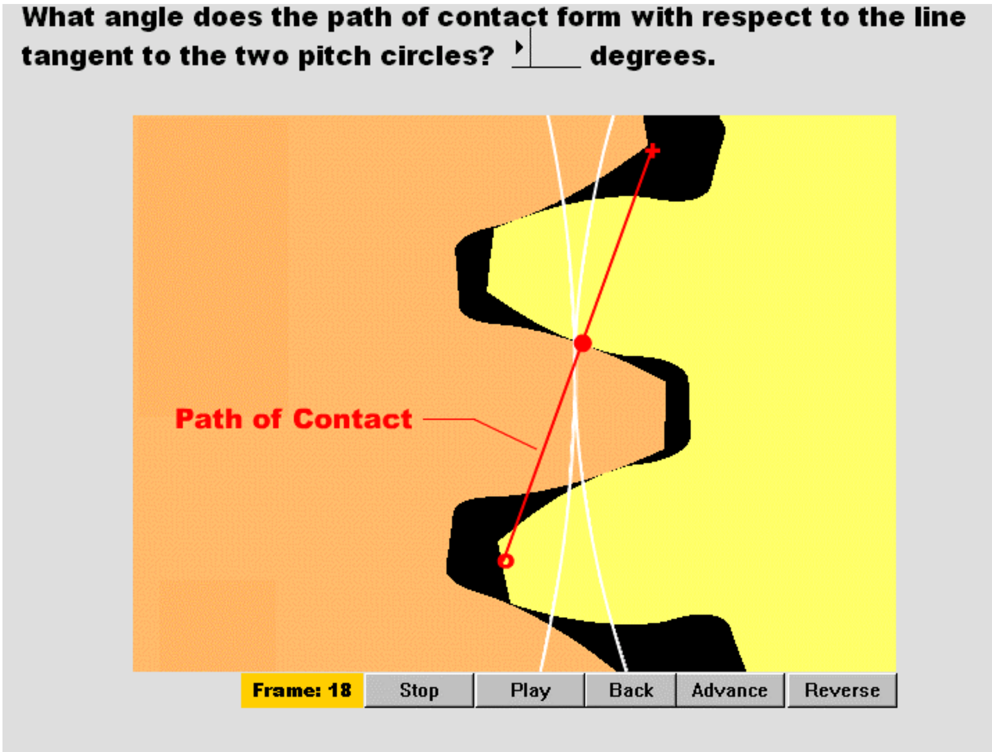

Fig. 3 - Sample Frame From the Third Animation Showing the Path of Contact

Before proceeding to the fourth animation, students are quizzed about the line of action and its relationship to the path of contact. This short quiz reinforces and verifies that students have mastered the material presented by the animation. Following their answer, students are again given immediate feedback about their quiz answer.

The fourth animation, illustrated in Figure 4, explores the forces, without friction, acting on the gear teeth during one complete contact cycle. The objectives of this animation and accompanying exercise are to: (a) demonstrate that the direction of the forces coincides with the path of contact, (b) that the load is equally split between the two points of contact when there are two points, and (c) that the maximum load occurs when there is only a single point of contact because the power transmitted remains constant throughout the contact cycle.

A class discussion was felt to be more appropriate in assisting the students to learn about the power transferred by gears and the notion of rolling motion at the point of contact. Students were to explain why the magnitude of the force doubles when the number of contacts points is reduced to one and why the forces, without friction, act along the path of contact. Alternatively, students could take this question up in an on-line threaded discussion or via e-mail contact with the instructor. These methods of learning are more effective for complex concepts and analysis. The point is that the more in depth the question, the more difficult it is to learn the material using the simple interactions currently available to computer-based-instruction software.

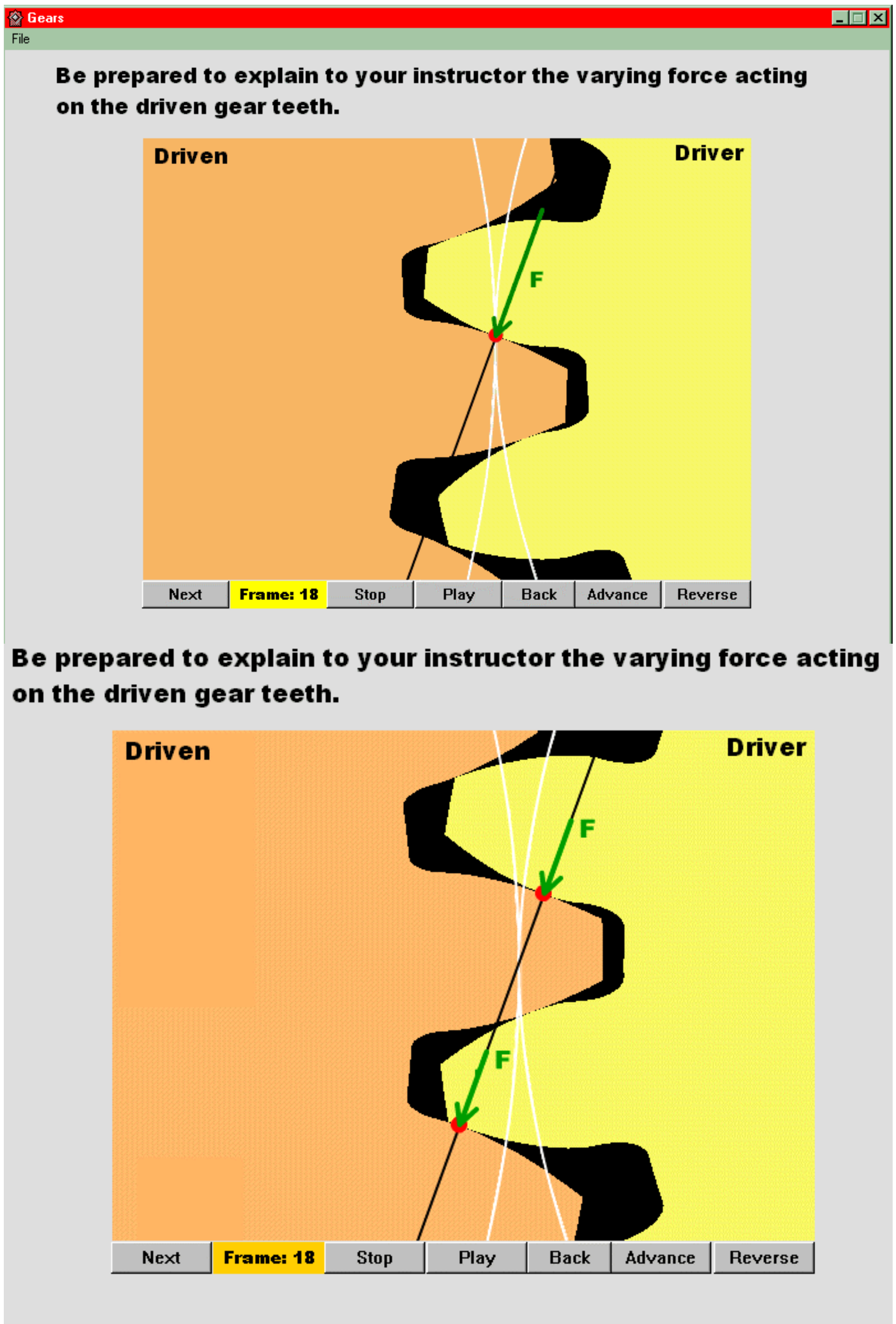

Fig. 4 - Sample Screens From Fourth Animation Demonstrating Normal Forces Acting on the Driven Gear Teeth

The fifth and final animation demonstrates the effect of all the forces, including friction, acting on the gear set during a complete contact cycle. A typical frame from the animation is shown in Figure 5. The objective of this animation is to illustrate that the direction of the friction force changes as the point of contact moves through the point of pitch circle contact. This is demonstrated in the animation as the friction force reverses its direction at the point of pitch circle contact. Students can explore this in detail by stopping the animation and then use the next and previous frame buttons to examine the transition frame by frame. In this manner, students can determine the precise point in the contact cycle where the friction forces makes its directional transition.

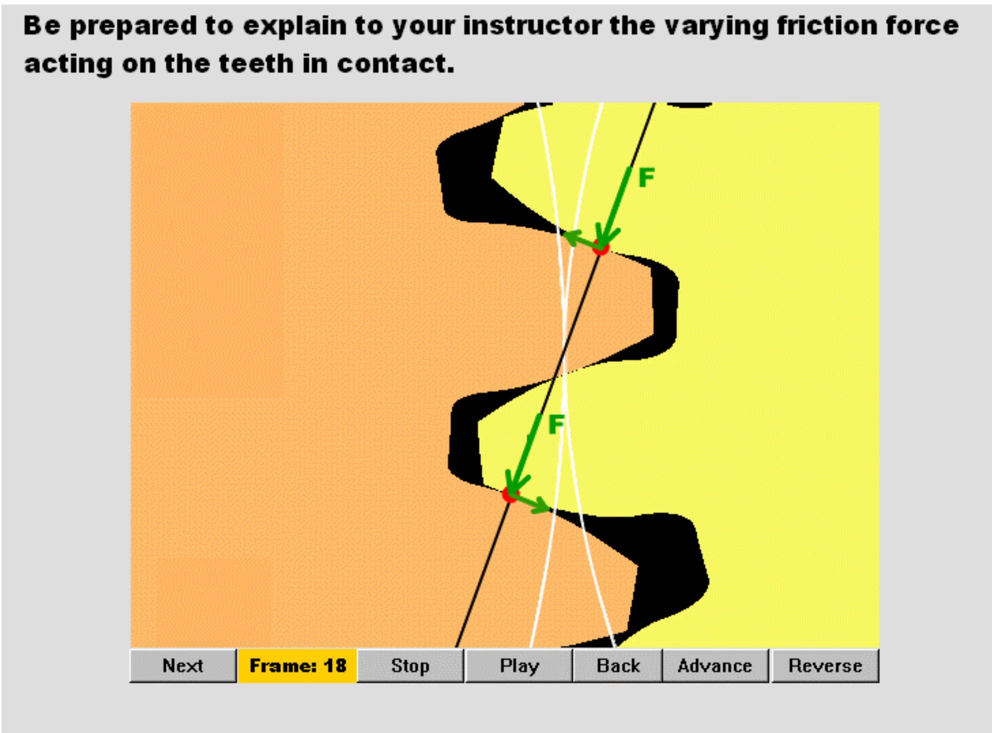

Fig. 5. Sample Frame of the Final Animation Illustrating the Forces Acting on the Driven Gear During a Contact Cycle

As with the fourth animation, this animation is used to stimulate classroom discussion. In particular, the students are coached with the message shown in Figure 5 to be prepared to discuss the role of the friction forces during the contact cycle. As pointed out in the preceding animation discussion, this knowledge is perhaps best learned using the discussion format rather than a simple CBI type interaction.

Conclusions

This simulation of the contact cycle of a gear set offers many advantages that cannot be achieved in a physical laboratory experiment as demonstrated here. Certainly one can make a movie of a physical gear set and allow students to analyze the movie frame by frame. Effectively, this is what this simulation is doing. But, in addition to providing a convenient means of doing a time-motion study of the gears; the superposition of lines, dots and arrows onto the gear set allows the student to better visualize, and consequently better understand, the kinematics and dynamics of the gear set.

The use of questions, immediate feedback, and stimulation of discussion actively engages students with the simulation. They cannot passively sit back and observe, as so frequently happens in lectures. Since they are now actively engaged with the material, the research of educators and cognition psychologists indicates that the students will have a better understanding of the material and will retain it longer. Hence, carefully constructed computer-based simulations can contribute significantly to the efficiency and effectiveness of learning from the perspectives of both the student and teacher.

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Edward E. Anderson
Dr. Anderson is currently a Professor of Mechanical Engineering at Texas Tech University where he also serves as the Associate Director of the Teaching, Learning, and Technology Center. His research interests focus upon heat transfer and student learning. He has developed numerous engineering computer based instructional modules in a variety of topics and uses many of these to gather data about student usage patterns and performance.