Use of an Affordable High Speed Video Camera for Visualization in Mechanical Engineering Courses

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Abstract

Methods for providing visualization of various phenomena in engineering courses can be beneficial to student learning. Animations created using software can provide students an excellent visual learning experience in some cases. Another approach is to produce slow-motion video recordings of actual high speed physical events. However, professional-level high speed video equipment can cost thousands of dollars. Due to budgetary constraints, expensive high-speed video equipment is not affordable for many academic programs. This paper describes use of an affordable "off-the-shelf" camera that can record video at up to 1000 frames per second (fps) to assist in the teaching of a mechanical vibrations course and a fluid mechanics course in a mechanical engineering curriculum. Examples used in the vibrations and fluid mechanics classes are overviewed, and lessons learned are discussed. In some cases, the slow motion video is used in conjunction with computer-based animations from a finite element analysis program, providing the students with an additional visual aid and also providing some validation for the students that results from the finite element analysis software are valid. The pros and cons of various camera settings, and also some limitations of this low-cost alternative, are discussed. Also, some advantages of combining video from the high speed camera with video from other sources, such as video from screencasting software, are illustrated.

Background

Educational benefits of using videos to capture phenomena are demonstrated in other works. One example is the work reported by Swanbom, et al., in which an off-the-shelf camera was used in a case where K-12 students learned about gravitational attraction and the motion of falling objects. That recent reference includes a significant literature review which can be consulted for further reading. Ashby and Asay discuss recent use of high-speed video in a university engineering setting in which undergraduate students studied the dynamics of a vehicle rollover with an ejected passenger. A test was performed that included the video recording of the rollover event. According to student surveys, the overall project, which included the high-speed video, was effective in enhancing student understanding of dynamics principles. Okçay and Öztekin used a video camera which could record at 30 frames per second in a fluid mechanics course as part of a Particle Image Velocimetry system that produces visualization of fluid flow. The authors concluded that projects involving this flow visualization system motivate students in the learning process. The idea of using video recordings of actual physical events in engineering courses is certainly not new or limited to fairly recent efforts. For example, in a much earlier effort, Walters, et al., utilized video recorded at 30 frames per second in an egg
drop experiment. Other examples can be found in the literature. The primary purpose of this paper is to illustrate some applications of camera use in two specific engineering courses with an available, relatively inexpensive high-speed camera.

The specific camera used in this work is the Casio Exilim EX-ZR100. This product was purchased because there was a desire to produce videos of moderately high speed events, but professional level high speed video equipment is prohibitively expensive, typically costing well over $10,000 for research-level equipment. The price of the unit used in this work was less than $300 at the time it was purchased in 2011. Similar products may be available. A full review of available equipment is not included here. This paper focuses on illustrating some classroom uses for an off-the-shelf camera that records at speeds above the usual 30 frames per second (fps) commonly found in hand-held cameras. The camera only records audio when the 30 fps setting is used. As discussed in the manual for the camera, for recording at 30 fps to 240 fps, the image size, in pixels, is 432x320. However, at 480 fps, the image size is reduced to 224x160 pixels, and at 1000 fps, it is reduced to 224x64 pixels.

This paper illustrates use of the camera first in the mechanical vibrations course, then in the fluid mechanics course, followed by a discussion of initial attempts at assessment and a summary.

**Mechanical Vibrations**

Mechanical vibrations at the University of Kentucky is a dual-level course including undergraduate students taking the course as an elective and graduate students taking the course for graduate credit. It is taught via ITV (Interactive Television), with undergraduate students at the extended campus program in Paducah, KY, taking the course simultaneously with undergraduate and graduate students on the main campus in Lexington, KY.

Initial efforts at incorporating slow motion video into the vibrations class have been focused on better explaining the concept of a mode shape for a mode of vibration and the relationship between a mode shape and system response to various inputs, such as the steady-state response to a sinusoidal forcing function for a lightly damped system. Videos from two physical systems will be discussed: (1) a long, flexible aluminum cantilevered beam, and (2) a spring/mass system which has a behavior essentially like that predicted for simple lumped-mass models which are often considered in vibrations textbook problems.

**Vibration System (1)**

In order to help students understand the meaning of beam vibration mode shapes, a simple aluminum cantilevered beam of rectangular cross-section 0.125” x 0.750” and length 50.5” was used. The beam was clamped in a vise. The clamped length was chosen simply by trial-and-
error, with the goal being to produce a structure that is stiff enough to behave such that linear system approximations are reasonable, but flexible enough that the vibration response amplitudes in the first and second bending modes can be easily seen. Two views of the system are shown in Figure 1.

Often, beam vibration mode shapes are indicated with a static figure showing the deformed shape at an instant of maximum deflection for motion in one specific mode. For a student learning the basics of vibrations, the meaning of this static figure may not be clear. Example static figures illustrating the first two bending mode shapes generated with the finite element software tool, ANSYS\textsuperscript{5}, are shown in Figure 2.

![Mechanical Shaker and Stinger](image1)

**Figure 1**: Flexible beam set up for vibrations demo.
Figure 2: Mode shape plots from an ANSYS finite element analysis.

Animation of the mode shape within finite element software is a powerful means for illustrating the motion corresponding to a specific mode. However, the relationship between a calculated mode shape and the actual response of a real-world structure seems difficult for some students to fully grasp. For example, during class in fall, 2012, as a beam mode shape was animated during a course lecture, a student inquired as to what the assumed input was producing the response. Undamped natural frequencies and mode shapes had been discussed at length at that point in the semester, and the students had calculated undamped natural frequencies and mode shapes for multiple degree-of-freedom (DOF) systems on assignments. The question clearly indicated a lack of understanding of the meaning of a mode shape. The mode shape calculated within the software was based on the standard method of neglecting damping and solving an eigenvalue problem involving the system mass and stiffness matrices. The response to any input, based on linear vibration theory, is a combination of contributions of the various modes. The contribution of any given mode depends on the input and the mode shape for the mode. This one student question provides only a small amount of anecdotal evidence that students have difficulty fully grasping the concepts involved. But, through years of teaching this topic, many similar questions have arisen. From this experience, it seems reasonable to conclude that while many engineering students can easily master the relatively simple mathematics involved in calculating natural frequencies and mode shapes at least for systems with small numbers of DOF, many don’t have a clear understanding of the impact of the various modes on the overall system response to various inputs.

A demonstration was developed using a series of videos recorded with the high-speed camera. This demo set-up was used for the first time in the class in Fall 2012. The video camera was used to record the motion of the beam in four main cases, with the overall point of the demo
being to illustrate how the mode shapes are related to the actual motion for various types of inputs for a lightly-damped system. The primary cases considered were:

a) Steady-state response when the beam is subjected to a sinusoidal forcing function with a forcing frequency very near the mode 1 natural frequency. For this case, mode 1 motion dominates for this lightly-damped structure. The mechanical shaker was used to excite the beam with the frequency input selected through use of a function generator. While it may seem unusual, the shaker input was implemented close to the clamped end of the beam. This may seem counterintuitive, and would not likely be the approach used in typical modal testing. However, in this case, the demonstration set-up was devised to produce large amplitude motion as compared to the motion usually encountered with engineering structures. The shaker stroke is small relative to the beam response amplitude for this case, except near the clamped end. So, in this case, it is not feasible to apply the shaker input anywhere except near the clamped end. This approach produced good results for the intended purposes.

b) Steady-state response when the beam is subjected to a sinusoidal forcing function with a forcing frequency very near the mode 2 natural frequency. For this case, mode 2 motion dominates for this lightly-damped structure. The same set-up was used for cases (a) and (b). The only difference was the frequency selected with the function generator.

c) Free response when the beam is subjected to an initial displacement configuration for which mode 1 motion dominates.

d) Free response when the beam is subjected to an initial displacement configuration for which mode 2 motion dominates.

The natural frequency for the first bending mode for this case (for motion in a plane parallel to the floor in Figure 1) is about 1.6 Hz, and the second bending mode for motion in the same plane is about 10.2 Hz. In this case, a standard frame rate of 30 fps produces reasonable results for viewing recorded motion that is dominated by the 1.6 Hz mode 1 response. The period of mode 1 motion is about 0.6 seconds, so at 30 fps, there are about 18 frames captured for each vibration cycle. This results in recorded motion that appears to be relatively smooth. However, even at this low response frequency, there seems to be some appearance of discontinuity in the recorded beam motion. The video does not appear quite like the perfectly smooth motion one would see when observing mode 1 response in-person. However, since there is higher resolution associated with the lower frame rate for the particular camera used, if only mode 1 motion were to be recorded, the lower frame rate might be preferable. It seems to be quite adequate for illustration purposes in an educational environment. For second mode motion, the period is about 0.1 seconds, so at a recording setting of 30 fps, there are only about 3 frames captured for each vibration cycle. Recording mode 2 motion at 30 fps produces an appearance of discontinuous, or
“jumpy”, motion. Sometimes there is an appearance of blurred motion. When a frame rate of 240 fps is used, there are about 24 frames captured per cycle of vibration which produces an appearance of mostly smooth motion and seems adequate for illustration purposes in an educational environment. A higher frame rate setting of 480 fps for this case does not seem to offer enough advantage in smoothing the appearance of the motion to offset a reduction in resolution and lighting in the recording that is encountered when this particular camera is set at this higher frame rate.

The motion recorded with high-speed video was seen to agree with that expected in each case (a-d) based on the mode shape plots in Figure 2. In addition to the videos of the actual beam motion, the demo included animation of cantilevered beam mode shapes using ANSYS. The agreement between the motion predicted by the software for motion in a given mode was evident when the mode shape animations were compared to the video recordings. It is somewhat difficult to adequately convey the nature of the content of the videos in a paper, but an attempt is made here with several figures.

Figure 3 shows five frames from the ANSYS animation of mode 1 motion at the top of the figure. These five frames illustrate one full cycle of mode 1 vibration, progressing in time from left to right. For comparison, the video recorded motion for case (a) at a 240 fps setting is shown at the bottom at approximately the same points in a cycle of vibration that are depicted in the corresponding ANSYS animation frames.

Figure 4a shows three frames from the ANSYS animation of mode 2 motion at the top of the figure. These three frames illustrate one-half cycle of mode 2 vibration, progressing in time from left to right. For comparison, the video recorded motion for case (b) at a 240 fps setting is shown at the bottom at approximately the same points in a cycle of vibration that are depicted in the corresponding ANSYS animation frames. To illustrate a pitfall with using a 30 fps setting for motion at this higher frequency, Figure 4b shows a screen capture of mode 2 motion recorded at this lower frame rate. The beam motion is blurred. In this particular case, there is one actual advantage to viewing the lower frame rate video. Mode 2 contains what is commonly referred to as a “node point”. The plot in Figure 2 shows this location on the beam which has no motion for mode 2. The blurry appearance produced with the lower frame rate setting very clearly reveals the location of this node point. Viewing the higher frame rate video, this “node point” is less obvious. This is a case where it can be advantageous to use multiple frame rate settings to record the same phenomenon. At the higher frame rate, it is clear that points on the beam between the node point and the clamped end are out-of-phase with points between the node point and the free end, which is in agreement with the plot for this mode in Figure 2. This phase difference is not clear in the video recorded at 30 fps.

Figure 5a shows the initial deflection pattern, imposed by hand, for case (c). A screen capture from the recording of the free response shows the response dominated by mode 1 motion, as expected. Figure 5b shows the initial deflection pattern, imposed by hand, for case (d). A screen
capture from the recording of the free response shows the response dominated by mode 2 motion, as expected. Note that a smart phone showing a stop watch application is included in the views of Figure 5. This is a simple, easy method to allow for a quick estimate of the frequency of the motion being observed. By counting some number of cycles, and dividing by the amount of elapsed time, the frequency is readily determined. It also produces a clear indication for the viewer that the action is being viewed in slow motion.

Figure 6 is included to provide some insight into the trade-off between using a higher frame rate of 480 fps as compared to a lower rate of 240 fps. As mentioned before, the particular camera used produces lower resolution and lower lighting recordings at higher frame rates. Under certain circumstances, the higher frame rates may be necessary to illustrate some phenomena. But, there is a cost in quality associated with using the higher rate settings. With careful consideration of lighting and background, acceptable results should be attainable for illustration purposes for many situations at the 480 fps setting.

![Figure 3: Top shows five frames from an ANSYS mode 1 mode shape animation. Bottom shows screen captures at corresponding points in one full vibration cycle from a 240 fps video illustrating harmonic motion dominated by Mode 1 response.](image-url)
Figure 4: (a) Frames from ANSYS mode 2 mode shape animation (top), and the corresponding screen captures from video illustrating one-half cycle of steady-state forced motion dominated by Mode 2 recorded at 240 fps (bottom). (b) Screen capture from video also illustrating steady-state forced motion dominated by Mode 2 recorded at 30 fps.
Figure 5: (a) Initial deflection pattern and screen capture from free response for a case dominated by mode 1 motion. (b) Initial deflection pattern and screen capture from free response for a case dominated by mode 2 motion.

Figure 6: Illustration of reduced resolution and lighting with increased frame rate.
The system considered is a simple translational spring-mass system. It was actually the first system for which the high speed video camera was used in the vibrations class. In this case, there were some lessons learned with regard to lighting and background, some of which are not specific to high speed video recording, but relate to recordings in general.

In Fall 2011, a video was produced using this system to illustrate for students the relationship between mode shapes and the free response to initial displacements for a system simple enough that calculation of natural frequencies and mode shapes is easily accomplished with a pencil, paper, and calculator. The system consists of simple springs and laboratory masses. Figure 7 is a screen capture from the video showing the system. Clearly, a more contrasting background and better lighting would improve the quality.

This case illustrates the approach of combining recordings from the camera with video from other sources. A final video was produced using the screencasting software, Camtasia Studio\(^7\), in which computer desktop work was recorded and combined with video recordings of the spring-mass system motion from the camera.

At left in Figure 8 is a depiction of the type of textbook system often considered in mechanical engineering course work that can be used to represent the actual simple physical system in Figure 7. In Figure 8, at right, is a screen capture that illustrates a use of screencasting casting software that seems effective. Information was overlaid on a screen capture of the video from the camera to illustrate for the students that the simple physical system is similar to the lumped mass models they have considered in homework assignments. Figure 9 shows the calculation of natural frequencies and mode shapes using MATLAB\(^6\) based on a mathematical model that included the masses and spring constants corresponding to the actual physical system. The initial portions of the video included single DOF system tests which were performed to deduce the spring constants. The portion of the video illustrated in Figure 9 was recorded with the screencasting software. Figure 10 illustrates additional instructional material inserted into the video using the screencasting software. In this particular case, the calculated mode 1 natural frequency is 3.747 rad/s (0.596 Hz) and the mode 1 mode shape vector can be written:

\[
\{A\}_1 = \begin{bmatrix} 0.625 \\ 1.000 \end{bmatrix}
\]

The calculated mode 2 natural frequency is 12.56 rad/s (2.00 Hz) and the mode 2 mode shape vector can be written:
Two primary cases were considered in the video recording for this system:

a) Free response when the system is subjected to an initial displacement configuration for which mode 1 motion dominates.

b) Free response when the system is subjected to an initial displacement configuration for which mode 2 motion dominates.

Figure 11a shows screen captures from the video illustrating the initial deflection pattern and the free response for case (a), which is dominated by mode 1 motion. These screen captures were of video recorded at 240 fps. A recording at 30 fps is adequate for this case when shown at real speed, but since the 240 fps video is, by default, played back in slow motion, there is some benefit to viewing the free motion as recorded at the higher frame rate.

Figure 11b shows screen captures from the video illustrating the initial deflection pattern and the free response for case (b), which is dominated by mode 2 motion. Again, these screen captures were of video recorded at 240 fps. A recording at 30 fps in this case appears somewhat “jumpy”, so there appears to be a clear advantage to using the 240 fps setting for case (b).

The motion recorded is consistent with what is expected for the free response for these cases based on the calculated mode shapes. For case (a), the masses move in-phase, and for case (b), the masses move out-of-phase. The video also included use of a smart phone showing a stop watch application, and excellent agreement was found between the frequencies of recorded motion and the calculated natural frequencies.
**Figure 7:** Two DOF spring-mass system.

**Figure 8:** Typical textbook system sketch at left and corresponding parameter definitions for the test system at right.
Figure 9: Illustration of MATLAB calculations inserted into the video.

Figure 10: Additional instructional material inserted into the video.
Figure 11: (a) Initial deflection pattern (left) and three screen captures from 240 fps video of the free response for a case dominated by mode 1 motion. (b) Initial deflection pattern (left) and three screen captures from 240 fps video of the free response for a case dominated by mode 2 motion.
Fluid Mechanics

Fluid Mechanics is a junior-level (undergraduate) course that covers all of the classical topics from fluid statics through turbomachinery and piping systems. The high-speed camera in the fluid mechanics course was used for qualitative flow visualization of the flow field entering a compressor. This supplemented the chapter on turbomachinery, which covers machine performance and the Euler turbomachine equation.

Turbomachines are common components that are used in countless machines that are used every day. This fact along with the availability of a low speed research compressor at the University of Kentucky campus in Paducah was the motivation for using the high-speed camera for the flow visualization for this course. Throughout the semester the subject matter being presented was also related to flow through turbomachines. For example, Bernoulli’s equation was used for the stagnation pressure in the inviscid core flow to determine the stagnation pressure at the machine entrance. Blades from aircraft gas turbine engines were used as props for class discussions. The concept illustrated is that velocity diagrams are used to design the blade camber with deviation being an important factor to be considered in determining the blade exit angle to get the correct work transfer from the turbomachine. One open question that was left until the movie of the compressor inlet flow field was whether the circumferential direction a turbine blade or compressor blade rotates can be determined by just looking at the blade shape.

The high-speed camera was used at the beginning of the semester to produce a movie of the inlet to the compressor. The movie was then inserted into a PowerPoint presentation with additional information concerning the compressor. The University of Kentucky Low Speed Compressor (LSRC) is a single-stage axial-flow machine consisting of one row of rotor blades followed by one row of stator vanes. There are 42 rotor blades and 40 stator vanes. The blades are painted black, which significantly helped with being able to “see them” in the video. The outer casing on the compressor has an approximately 100º section of clear Plexiglas that permits a view of both the rotor blades and stator vanes. In addition, there is a small glass window in the casing above the rotor blades that provides better optical access in this area, as presented in Figure 12.

As with all photography, lighting was a major issue. In addition to lighting, the combination of resolution and frame rate was crucial. As the frame rate increases the viewable area available decreases for this particular camera. It was discussed earlier that the resolution is reduced with higher frame rates. In order to have a large enough area of the annulus to increase the effectiveness of the video recording, the frame rate was decreased. The drawback of decreasing the frame rate was that the rotational speed of the compressor had to be decreased in order for the video to resolve the individual blades rotating through the field of view. The design rotational speed of the compressor is 900 RPM (revolutions-per-minute). Through experimentation with frame rate and viewable area it was found that the rotational speed of the compressor needed to
be decreased to 200 RPM with a frame rate of 480 fps. The low rotational speed did not have any impact on the concepts being presented, but did have an impact on machine performance.

It was desirable to get a view of the entire span (height) of the rotor blades. Hence, the camera was placed at the inlet to the compressor, which is shown in Figure 12. To increase the lighting in the compressor inlet region a portable lighting stand with halogen lights was used. The overhead lights in the room did not have any impact on the overall quality of the video using a frontal view.

![Bell Mouth Inlet with Viewable area for video](image)

**Figure 12:** Frontal view of the University of Kentucky low speed research compressor.

A theatrical fogger was used to introduce ‘smoke’ into the flow stream for flow visualization. There is a relatively long length in the flow direction from the inlet plane to the rotor blade leading edge plane – roughly 0.33 m. Hence, the position of the fogger relative to the bell mouth inlet had to be considered in order to minimize the dispersion of the smoke as it flowed through the inlet to the rotor inlet plane. It was found that placing the fogger near the edge of the bell mouth inlet so that the smoke stream accelerated around the bell mouth lip provided the best results. Figure 13 illustrates one frame from video showing the smoke entering the rotor blades. The plume of smoke was found to spread-out filling about half the annulus. The smoke puffs were mostly generated by the fogger, which did not emit a steady stream. Other methods of introducing the smoke for flow visualization will be considered in the future.
Figure 13: Single frame from video illustrating flow entering the axial flow compressor.

Assessment

More effort needs to be expended in future work on assessing the educational value of videos such as those described in this paper. At this point, the authors are still considering ways to most effectively utilize this technology. An initial attempt at gauging the effectiveness of these early efforts was made by soliciting input from the vibrations students in Fall 2011 who had watched the video pertaining to “Vibrations System 2”, the 2-DOF spring/mass system. The students were given a practice quiz before they watched the video, which was optional and did not affect their grades. The video was, in part, related to the practice quiz questions. Watching the video was also optional, but a small amount of bonus homework credit was given to students who watched the video and provided feedback. This assessment method is far from perfect, as the students did not provide anonymous comments. Their names were attached to their emailed feedback in order to allow for assignment of bonus credit. There was an attempt made to convey to the students that an honest assessment was being sought and there was certainly no penalty for providing criticism. Realistically, though, with grades at stake, many students are unlikely, for obvious reasons, to make negative comments on anything an instructor does when the comments are directed to the instructor. With the assessment method in mind, the feedback from the students on two questions is provided here. The high ratings for this video certainly can’t be taken as solid evidence that the video was effective. Some added comments, which were encouraged, may provide some insight to the usefulness from the students’ perspective. Future efforts should entail a more reliable assessment approach.

Twenty-two students answered the following question:

Question 1: Did the video aid your understanding of how the mode shapes relate to system response? Answer on a scale of 1-10, with 10 being “very much” and 1 being “not at all”.

Average rating = 8.3

The following comments were added by students. Not all students added comments. They are provided in unedited form:
Yes the video definitely aided, especially in the ability to envision the movement better, so I rate its help as a 10... Because while I understood it all really well beforehand, I'm the type that retains things even better when I can "see" (envision) them.

This presentation helped my understanding of how the mode shapes relate to system response. I would give it a 5, just because I felt like I already had a good grasp on this concept before the video. However, had I not already understood how system response is affected by the mode shapes, I would rate this video much higher.

It did, and around 8 at first time I watch this video, but the second time I understand it (10)

(7) It helped having a visual representation of the calculations and math shown in class.

7, very helpful

On a scale of 1-10 I give the video a "9" of aiding my understanding if mode shapes and how they relate to system response. I tend to learn more as a hands on time learning and being able to see, what we have been studying, allowed me to connect the dots and make a little more sense of what's been going on! Thanks for video!

If I watched the video, it help to improve my understanding of how mode shapes relate to system response for the system free response. I would give a 9.

Yes, the video helps in understanding the mode shapes. I would rate it 8 on a scale of 1-10 because the visual is very helpful in understanding what’s going on on paper.

Yes, the video helped. I liked the visual. I would say a 9 out of 10.

8. It could be better if the initial conditions were set with the help of a ruler to get more precise displacement. But the frequencies from experiments are very close to prediction. So I think it's very good.

Rating of 4/10. It was interesting but I understood it pretty well prior to watching the video, so it didn't help me very much.

The video helped me visualize the mode shapes a lot. I'd give it a 10! (+5 points for watching my professor commandeer a swing set frame in the name of science!)

It added to my understanding. I think I also watched some YouTube videos before about the same thing. So combined it was 10/10 "helpfulness".

10. The demonstration was easy to follow and provided an easy comparison of the mode shape theory and its real-life application. I was surprised at how repeatable the oscillation periods were and how much effect the initial displacements had on the oscillations.
I already knew how the masses would act but the video was a good refresher. 6 out of 10.

Yes, it helped a lot. I think it deserves 10 on the scale of 1-10. Thank you.

Twenty-two students also answered the following question:

**Question 2:** If you had watched the video before answering the practice quiz questions, do you believe it would have helped? Answer a, b, or c:

a) It probably would have helped.

b) It would not have helped because I already understood and did well on the practice quiz.

c) It would not have helped. I didn’t understand it very well before the quiz and I still do not after watching the video.

Numerical results:

- Number answer a = 16
- Number of students answering b = 6
- Number of students answering c = 0

The following comments were added by students. Not all students added comments. They are provided in unedited form:

- B The question I missed on the quiz had to do with forcing functions and this was not shown in the video understandably because is hard to show periodic forcing in a simple real life example.

- a. It was helpful to physically see the motion based on each mode shape.

- a) it probably would have helped. I did understand mode shapes VERY WELL prior to this, but if I had seen the video first I would have had that reminder of how to calculate t correctly --- which is what I needed most (as embarrassing as that is to admit).

- B -- This video would not have affected my answers to the quiz because I understood these concepts at the time and did well on the quiz.

- A) it probably would have helped.

- My answer is b) I don’t think it would have improved my score on the practice quiz because I already understood the concept prior to taking it.
- Answer B - I got a 2/4 on the quiz because I made a careless mistake on the first problem which caused me to miss the second one as well.

- If I had watched the video ahead of time, I think it would have helped, so A. (+5 points for stream-of-consciousness style narration!)

- a) It probably would have helped.

- a. It would have helped. I understood the mathematical approach to the problems, but would always think for a bit on how the mode shapes actually physically related to the system. Thank you for posting the video and taking the time outside of class to further teach the concept.

Summary and Conclusions

Initial efforts have been overviewed related to using an inexpensive high-speed video camera to illustrate concepts in mechanical engineering courses. The equipment probably does not produce the quality of videos needed for most research undertakings, but with the overall cost of this system at less than $300, and the cost of professional-level high-speed video equipment typically being greater than $10,000, the low cost approach outlined here may be the only option for capturing moderately high-speed events for illustration purposes for many instructors in engineering classes. Future work is planned using this basic approach for illustrating concepts in various courses, with improvements implemented based on lessons learned to date.

Some lessons learned are:

- A loss of resolution and reduced viewable area for higher frame rates must be considered for any specific application.

- Particular attention to lighting and background contrast is important for most videos, but these issues are very important when using a camera such as the one used in this work when a higher frame rate setting is selected.

- It is probably best in most cases to use the lowest frame rate setting that still allows for good visualization of the phenomenon being illustrated.

- Sometimes using high frame rate video and also standard frame rate video (such as 30 fps) for the same phenomenon can be effective, as noted in the case of the second beam bending mode response case that was discussed. In that case, the blurring seen in the video that was produced with the lower frame rate clearly revealed the presence of the node point location along the beam for the second vibration mode.
There can be some advantages in combining video from the high speed camera with video from other sources, such as video from screencasting software. Examples are the overlaying of labels on screen frames from the camera video shown in Figure 8, and the insertion of numerical calculations and other instructional information shown in Figures 9 and 10.

Technology will likely improve. Better inexpensive equipment may become available. So, some considerations noted in this paper may become less important over time. The primary point of this paper was to illustrate that even in tight budget situations, there is the possibility of enhancing course lecture material with videos produced with moderately high frame rates for certain types of situations studied in engineering courses.

References


5 ANSYS, Copyright 2009, SAS IP, Inc., http://www.ansys.com
