

A Variety of Applications of High-Speed Photography at Outboard Marine Research Center

PAPER J-4

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The various products of the Outboard Marine Corp. all receive attention at the Research Center. Studies made by this group include noise reduction, vibration analysis and control, combustion study, ignition study, structural analysis, etc. In every one of these varied assignments high-speed photography has played an important part. One significant problem involving both noise and vibration is caused by the flexibility of the crankshaft and crankcase of the outboard motor. High-speed photography has assisted in analyzing the frequency, modes and amplitudes of the motion involved.

The high-speed camera was used very effectively to analyze the damaging action which takes place when an outboard motor strikes an object in the water. This work was associated with the development of hydraulic shock absorbers on the high-powered outboards. Lawn mowers and chain saws have received the attention of the high-speed camera in analyzing the cutting action of the respective blades. Other problems involving these two products have also been studied by this means.

HIGH-SPEED PHOTOGRAPHY at the Research Center of the Outboard Marine Corp. has been a versatile tool, used in many ways to assist in project work, to aid in solving product design problems and to help develop production tooling. It has provided a visual aid to augment, verify and complement other analytical means. At other times, it has been the sole source of qualitative and quantitative instrumentation. It has been a constant means of stimulating and exciting curiosity in the action of various phenomena relating to all the Corporation's products. It is due to this versatility that the high-speed camera has become such a valuable tool in the Research Center laboratory.

Photographic Equipment and Methods

The equipment used for all applications described here has been a Wollensak Fastax camera with three lenses (a 25mm and a 50mm Wollensak, and a 35mm Leitz). The time control (the Goose) was built in our own laboratory and fulfills the same purpose as commercially built controls. Lights, as a rule, have been R-750's, although other standard lights have been used at times.

Black-and-white film is used in most applications since it can be developed and viewed within an hour or so compared with a day or more required for color. This is an important consideration when setup costs are important and when the urgency to accomplish a job is great. Color film is used where color contrast helps to define boundaries and points of contact, and in other ways to enhance the interpretation.

Film processing is normally done by commercial processors; however, when the subject matter is confidential or time is important, the processing is done in our own laboratory.

When the event photographed occurs but once or twice on the film, the few feet containing the event are made into a loop so that it may be projected in a continuously repeating manner. The observer may then

watch it without the interruptions resulting from reversing, rewinding and viewing those portions of the film which do not contribute to the analysis. This method is also valuable when two or more events showing a progression or a contrast of motion are to be studied. Sections of both films are then spliced into a single loop. The minimization of time between the viewing of the events aids in the analysis.

Following are descriptions of a few of the applications of high-speed photography which have been made at the Research Center.

Outboard Motor Applications

Vibration and Noise: Our organization has continually been noise conscious. This has resulted in increasingly improved standards of boating acceptability.

As major engine noises have been reduced, other noises have been unmasked. This has also been true of vibrations. In the normal evolution of the current models of outboard motors, a very significant problem involving both noise and vibration has arisen. This is a harsh noise accompanied by a vibration, usually most severe at particular engine speeds. It apparently is due to the flexibility of the crankcase and crankshaft, usually thought to be fairly rigid structures.

Various means of instrumentation such as strain gages, accelerometers and displacement detectors, have been used to analyze the conditions contributing to such noise and vibration. To these means high-speed photography has been added. Each one of these tools has contributed toward an understanding of the source, modes, frequencies, amplitudes, etc., which are involved in this complex study.

Figure 1 shows the setup used to photograph the motion of the flywheel end of the crankshaft of an outboard motor. A sharp-tipped cone was added to the end of the crankshaft. All of the cone with the exception of the tip was painted flat black. R-750 bulbs illuminated the conical tip. This point of light traced the path of motion of the end of the crankshaft. A grid composed of concentric circles, machine-scribed in Lucite, was mounted immediately above the illuminated tip.

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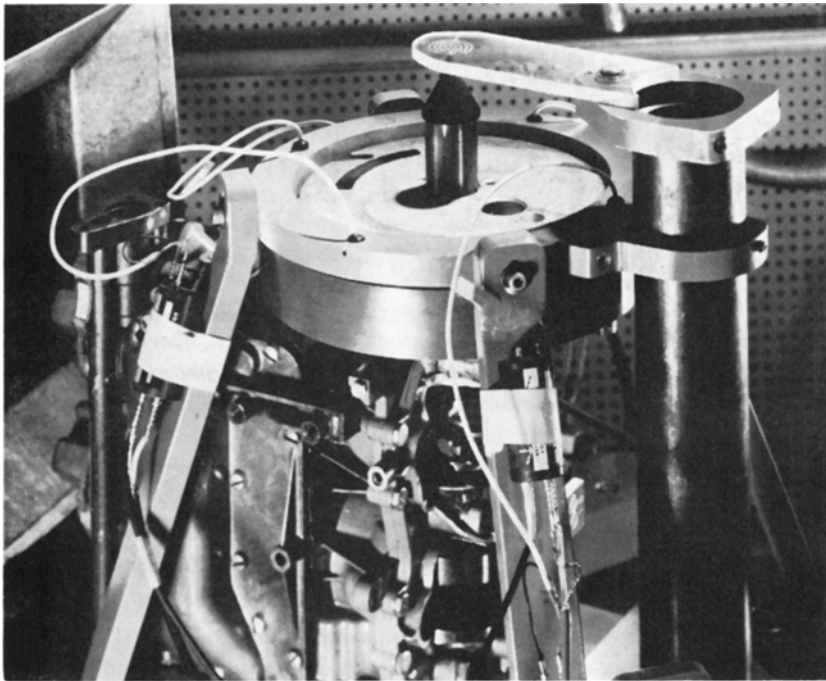


Fig. 1. Setup for photographing motion of flywheel end of outboard motor crankshaft.

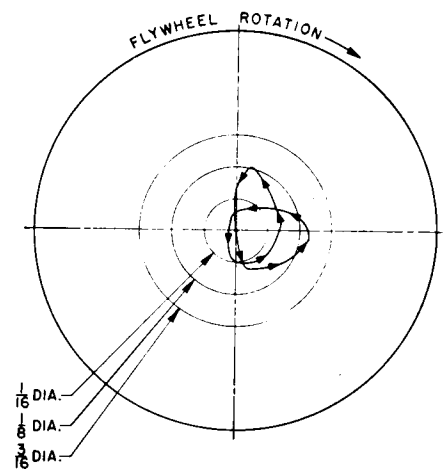


Fig. 2. Path of motion of illuminated indicator in Fig. 1.

The Fastax camera was placed 8 in. above the indicator. Focus of the 2-in. lens was obtained by placing a $\frac{1}{2}$ -in. adapter plate between the camera and lens mount.

Figure 2 shows the path of the illuminated indicator. The motion pictures show this path to be formed by a counterclockwise motion, although the crankshaft turns clockwise. There are two unsymmetrical cycles for every revolution of the crankshaft. The magnitude of vibration varies with the speed and can be estimated very closely, using the concentric circular grid as a reference. The magnitude of vibration shows up greatest at the engine speed at which the harshness is the worst.

Shock Absorbers Lower Impacts: If a high-powered outboard motor, propelling a boat at relatively high speeds, strikes an object in the water, the impact will tend to tilt the motor forward with great force. This sudden tilt, together with the rebound returning the motor to its original position, can result in broken mounting brackets and a damaged boat transom. Shock absorbers to cushion this motion were deemed essential on the 75-hp models.

A laboratory test utilizing the high-speed camera was established to measure the rotational velocities of the engine resulting from such an impact. Figures 3 and 4 show the test setup. The engine is mounted on a fixed bracket. A cart weighing approximately the same as the engine is propelled on a track at a controlled and measured velocity. When the mass hits the lower extremity of the motor, the motor reacts as it would if it struck an underwater object.

Angular motion is measured on a large protractor placed behind the motor. Time is measured by a segmented disc rotated by a 60-rps clock motor.

The laboratory test setup provided a means of obtaining design data under controlled conditions. The final test, of course, was during normal boat operation. Many films were taken showing a motor striking a submerged object while propelling a boat at speeds up to 35 mph.

Motion pictures were taken during various stages of development of the shock absorbers. From these films,

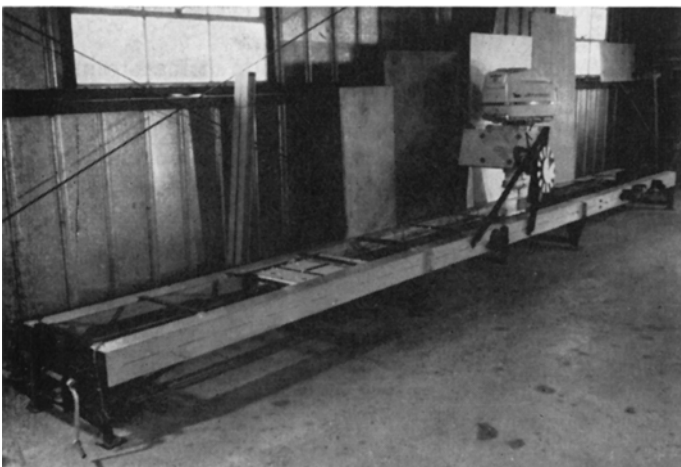


Fig. 3. Arrangement for measuring effect of impact on outboard motor when it strikes underwater object.

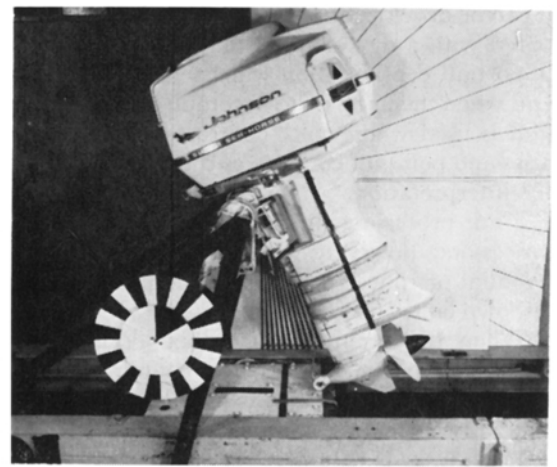


Fig. 4. Position of motor of Fig. 3 after impact, with measuring devices.

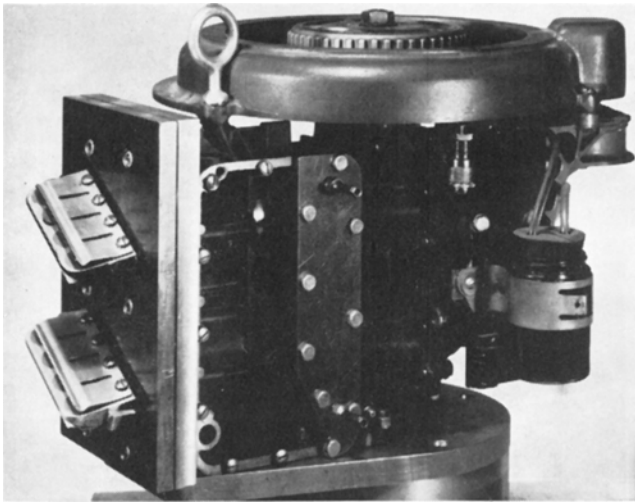


Fig. 5. Mounting of reeds outside engine to permit photographing action in fatigue study.

curves showing the angular velocity with respect to time were plotted for each developmental change in the shock absorber. This was the only instrumentation used.

Reed Valves: Fatigue failures of reed valves have been increasingly numerous as the horsepower of the engines has increased. Research has indicated that in order to evaluate the problem and find its solution, not only is it necessary to determine the peak stress value at impact but also it is important to make a visual observation of the reed action. Photographing the action under normal conditions is difficult since the valves are normally enclosed within the engine casting.

A test setup used the powerhead of an outboard motor driven by an electric motor. This became a pulsating pump actuating the reeds, which permitted the reeds to be externally mounted and to exhaust to the atmosphere. Thus, they were visible and easily photographed. The action when the reeds operate in this manner is similar to that under normal conditions. It was not possible, however, to operate at as high an engine speed as is normal. Some valuable pictures were made, nevertheless, at 5000 frames/sec. Figure 5 shows the setup described.

Further work is being done to attempt to photograph the reeds in their normal position in the engine. Lighting is the difficult problem. Figure 6 is a schematic diagram showing the proposed lighting of the reeds. Preliminary checks have shown that this method will probably produce excellent results.

Explosions in Powerhead Enclosure: Complete enclosure of the powerhead of the outboard motor became important for noise control. This caused concern over the hazards which might result from an explosion of fumes which could accumulate within this enclosed area. Explosion doors and quick release latches were designed to allow expansion of the gases without shattering the cover, which might result in flying fragments. In order to verify the design, explosions were created by the introduction of propane gas into the cavity and igniting it with a spark gap. The explosions were photographed at about 5000 frames/sec. The valuable information which was obtained from the films has resulted in a design considered safe.

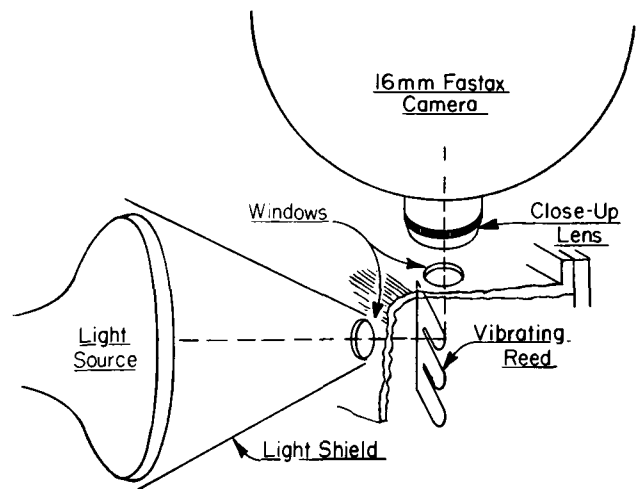


Fig. 6. Proposed lighting for photographing reeds in normal position in engine.

Lawn Mowers

Blade-Tip Design: A constant attempt is being made to reduce the danger resulting from a lawn-mower blade propelling an object such as a stone, a piece of wire or other items often found on a lawn. The problem readily lends itself to mathematical analysis. By knowing the size, weight and shape of an object, the speed of the blade and other physical parameters, the velocity and inertia of the object can be calculated for any design of blade tip. Based on certain assumptions as to the pellet size and blade speed, calculations of velocity and inertia were made for various blade designs. It was necessary to use an electronic computer to handle the quantity of mathematics involved. From the results of this approach, different types of blades were constructed. Several means of instrumentation were used to verify their design.

High-speed photography was also a great asset in this study. A test fixture consisting of a rotating lawn-mower blade, a steel pellet on a platform which is moved at the desired moment into the path of the blade, and a device to measure the velocity of the pellet is shown in Fig. 7. The Fastax camera was mounted above the fixture so as to photograph the contact of the blade with the pellet. Figure 8 shows the blade, the pellet, the clock and a tape marked off in 1-in. increments. The velocity measuring device, together with the high-speed motion pictures, verified the theoretical approach.

Lifting and Cutting Action of Blades: The design of a rotary lawn-mower blade is based not only upon its ability to cut grass, but also upon its ability to impart a lifting action to the blades of grass. High-speed photography has been used for comparing various blades in respect to these abilities. In the laboratory a transparent plastic housing was mounted on a test fixture which allowed a patch of grass to move under a mower blade driven by an electric motor. Figure 9 shows this setup. Photographs were made from several angles to show the lifting and cutting action.

Films have also been made to show a lawn mower operating on a lawn. In this case, the camera was mounted on a platform within a few inches of the ground. The platform and the mower were attached by a framework so that the camera remained a fixed distance ahead

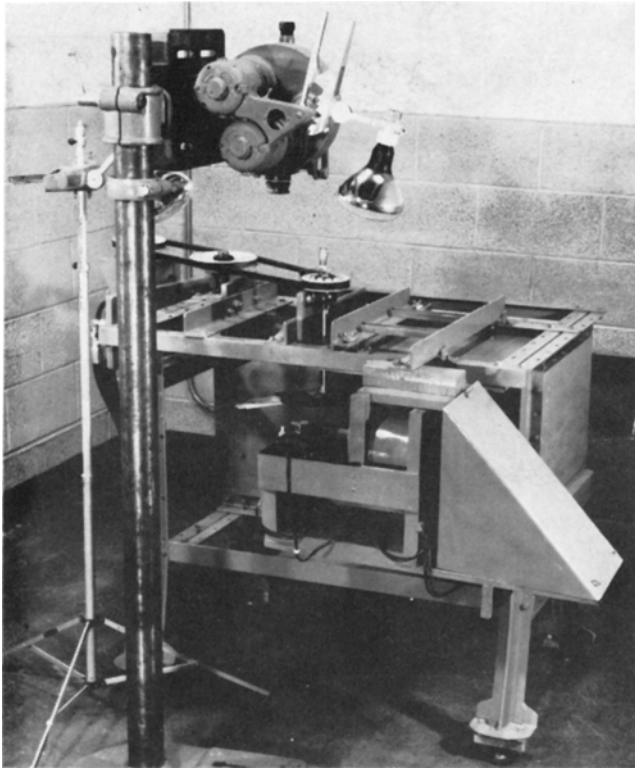


Fig. 7. Test setup for photographic study to improve design of lawn-mower blade tips.

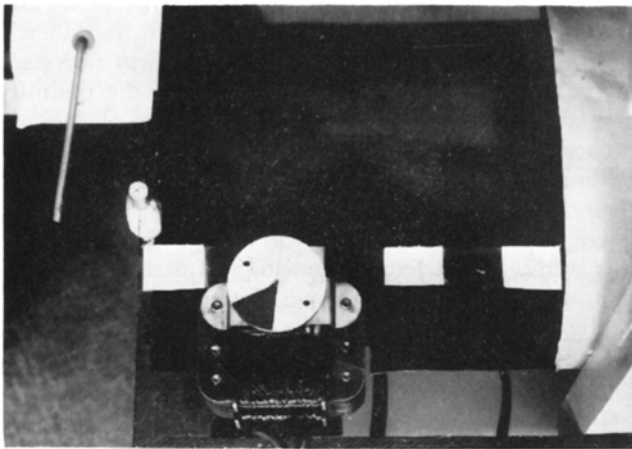


Fig. 8. Details of Fig. 7 setup.

of the front edge of the mower. Black-and-white film was used at first. It was found that the black-and-white pictures were more readable if the grass was sprayed with aluminum paint prior to cutting. Later on, color film was used. For these films, the blade was painted red to contrast with the color of the grass. The cutting edge of the blade, however, was painted aluminum. This produced greater definition between the grass and the blade at the time of cutting. Sunlight, reflected by several mirrors, was used as a light source.

Chain Saws

Figure 10 shows a test fixture used to photograph the actions of chain-saw teeth during wood cutting. The purpose of this study was primarily to aid in the development of tooth shape. Ultimately, however, various

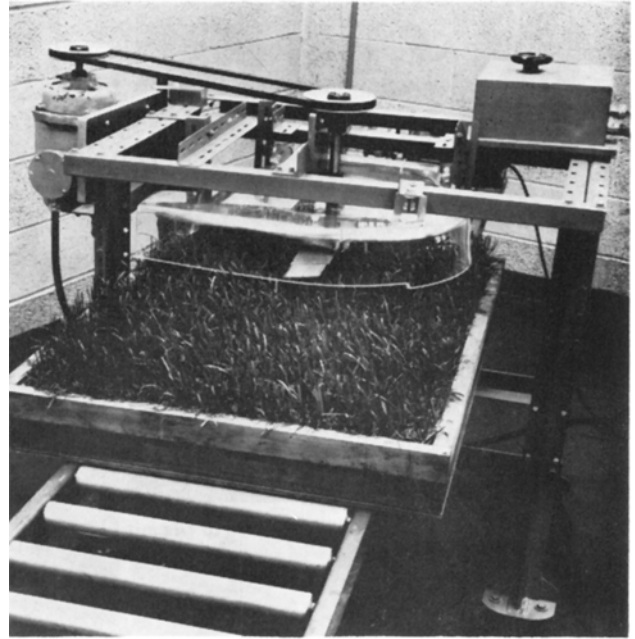


Fig. 9. Equipment for study of lifting and cutting action of lawn-mower blades.

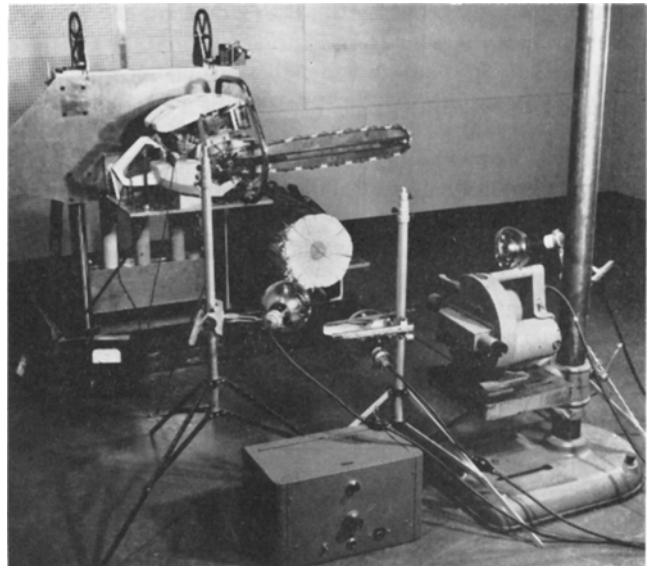


Fig. 10. Test fixture for photographic investigation of action of chain-saw teeth during wood cutting.

other problems were solved by means of the fixture and high-speed photography.

The pictures were shot through a "window" which was also one side of the saw kerf. Lucite was found to be less vulnerable to damage than plate glass and other types of glass. Several cuts could usually be made with one "window" before it became scratched and had to be replaced.

Color film provided greater readability in this application. Differentiation between the wood, the moving saw teeth and the cutter bar was not distinct with black-and-white.

R-750 bulbs were used to light the subject. Light placement, focusing and other preparation were done with the lights operating at reduced voltage to prevent warping of the Lucite.¹

High-speed photography was also used to help the Engineering Department determine tolerances on rake angle, predict wear on out-of-tolerance parts and evaluate the necessity of maintaining specified chain tension.

Conclusions

These are only a few of the many applications of high-speed photography at the Outboard Marine Research Center. No profound or unique photographic methods

have been used, nor has any of the work contributed much to the advancement of the art. But it is hoped that the discussion of the variety of applications will demonstrate the versatility of this photographic technique.

Edit. Note: The Fastax camera applications described above, and other applications, were illustrated in a motion picture shown at the Congress.