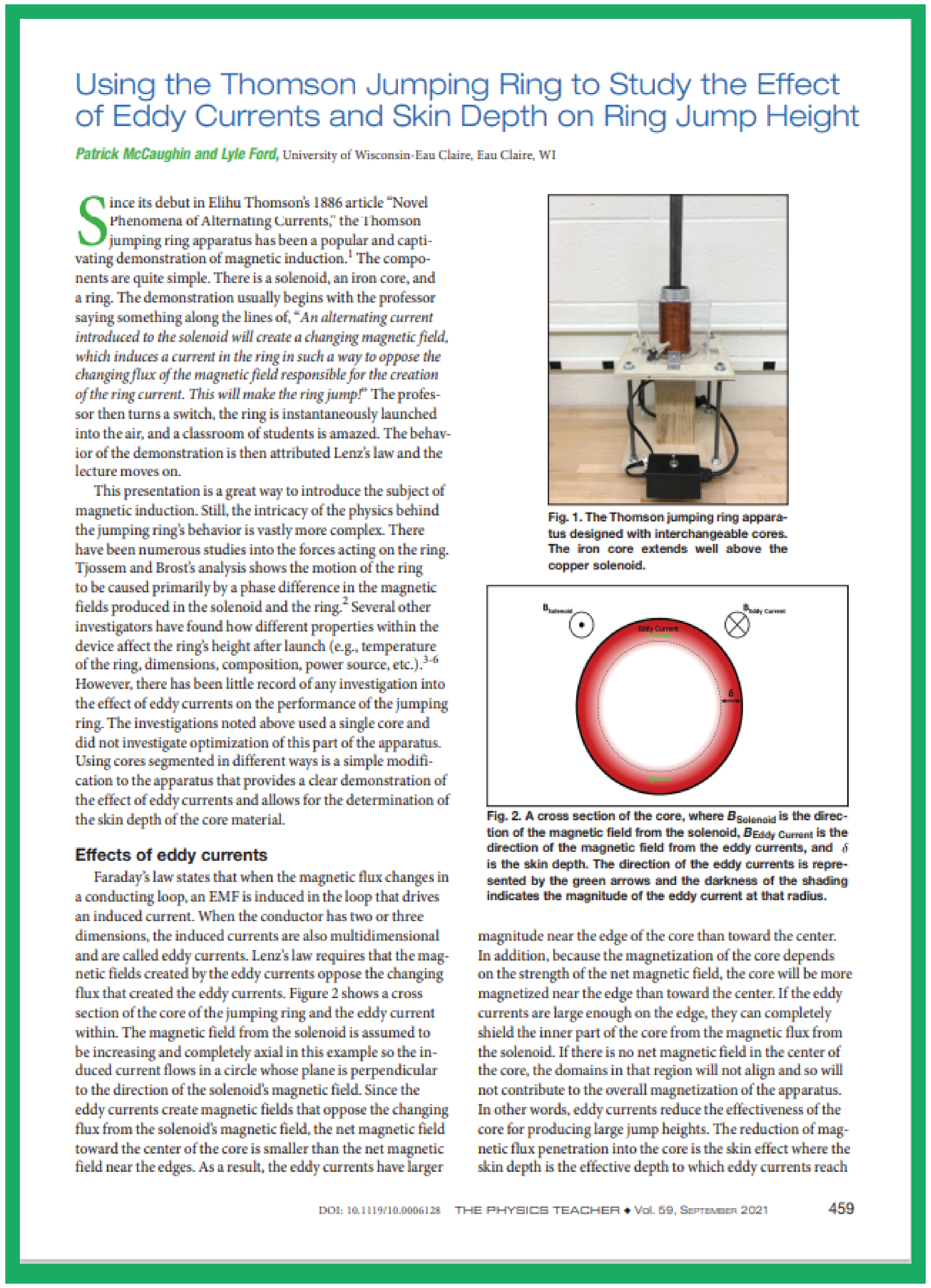
Lyle Ford

Professor
Department of Physics
and Astronomy

The Physics Teacher Vol. 59

Using the Thomson Jumping Ring to Study the Effect of Eddy Currents and Skin Depth on Ring Jump Height

The Thompson Jumping Ring has been used in physics classes for over 100 years to dramatically demonstrate magnetic induction. While most parts of the apparatus have been extensively studied and reported on, the iron core at the center has been given little attention. We showed that substituting different cores can provide an effective illustration of how the electric currents induced in the core can affect the performance of the apparatus and also provide a way to measure how far electromagnetic waves can penetrate into conductors.



Using the Thomson Jumping Ring to Study the Effect of Eddy Currents and Skin Depth on Ring Jump Height

Patrick McCaughin and Lyle Ford, University of Wisconsin-Eau Claire, Eau Claire, WI

Since its debut in Elihu Thomson's 1886 article "Novel Phenomena of Alternating Currents," the Thomson jumping ring apparatus has been a popular and captivating demonstration of magnetic induction.[1] The components are quite simple. There is a solenoid, an iron core, and a ring. The demonstration usually begins with the professor saying something along the lines of, "*An alternating current introduced to the solenoid will create a changing magnetic field, which induces a current in the ring in such a way to oppose the changing flux of the magnetic field responsible for the creation of the ring current. This will make the ring jump!*" The professor then turns a switch, the ring is instantaneously launched into the air, and a classroom of students is amazed. The behavior of the demonstration is then attributed Lenz's law and the lecture moves on.

This presentation is a great way to introduce the subject of magnetic induction. Still, the intricacy of the physics behind the jumping ring's behavior is vastly more complex. There have been numerous studies into the forces acting on the ring. Tjossem and Brost's analysis shows the motion of the ring to be caused primarily by a phase difference in the magnetic fields produced in the solenoid and the ring.[2] Several other investigators have found how different properties within the device affect the ring's height after launch (e.g., temperature of the ring, dimensions, composition, power source, etc.).[3-6] However, there has been little record of any investigation into the effect of eddy currents on the performance of the jumping ring. The investigations noted above used a single core and did not investigate optimization of this part of the apparatus. Using cores segmented in different ways is a simple modification to the apparatus that provides a clear demonstration of the effect of eddy currents and allows for the determination of the skin depth of the core material.

Fig. 1. The Thomson jumping ring apparatus designed with interchangeable cores. The iron core extends well above the copper solenoid.

Fig. 2. A cross section of the core, where $B_{Solenoid}$ is the direction of the magnetic field from the solenoid, $B_{Eddy\ Current}$ is the direction of the magnetic field from the eddy currents, and δ is the skin depth. The direction of the eddy currents is represented by the green arrows and the darkness of the shading indicates the magnitude of the eddy current at that radius.

Effects of eddy currents

Faraday's law states that when the magnetic flux changes in a conducting loop, an EMF is induced in the loop that drives an induced current. When the conductor has two or three dimensions, the induced currents are also multidimensional and are called eddy currents. Lenz's law requires that the magnetic fields created by the eddy currents oppose the changing flux that created the eddy currents. Figure 2 shows a cross section of the core of the jumping ring and the eddy current within. The magnetic field from the solenoid is assumed to be increasing and completely axial in this example so the induced current flows in a circle whose plane is perpendicular to the direction of the solenoid's magnetic field. Since the eddy currents create magnetic fields that oppose the changing flux from the solenoid's magnetic field, the net magnetic field toward the center of the core is smaller than the net magnetic field near the edges. As a result, the eddy currents have larger magnitude near the edge of the core than toward the center. In addition, because the magnetization of the core depends on the strength of the net magnetic field, the core will be more magnetized near the edge than toward the center. If the eddy currents are large enough on the edge, they can completely shield the inner part of the core from the magnetic flux from the solenoid. If there is no net magnetic field in the center of the core, the domains in that region will not align and so will not contribute to the overall magnetization of the apparatus. In other words, eddy currents reduce the effectiveness of the core for producing large jump heights. The reduction of magnetic flux penetration into the core is the skin effect where the skin depth is the effective depth to which eddy currents reach