Implementing and Deploying Magnetic Material Testing as an Online Laboratory

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Abstract. Hysteresis loop tracing (HLT) experiment is an undergraduate experiment for physics and engineering students to demonstrate magnetic properties of ferrite materials. In this paper, we explore a new approach of setting- up triggered testing of magnetic hysteresis via a remotely controlled loop tracer. To aid student learners, through an experimental design, we focused on factors such as analytical expression of mathematical model and modeling of reversible changes, which were crucial for learning hysterisis components. The goal was to study the phenomena of magnetic hysteresis and to calculate the retentivity, coercivity and saturation magnetization of a material using a hybrid model including simulation and remotely controlled hysteresis loop tracer. The remotely controlled equipment allowed recording the applied magnetic field (H) from an internet-enabled computer. To analyze learning experiences using online laboratories, we evaluated usage of online experiment among engineering students (N=200) by organized hands-on workshops and direct feedback collection. We found students adapted to use simualtions and remotely controlled lab equipment augmenting laboratory skills, equipment accessibility and blended learning experiences.

Keywords: virtual labs, Ferromagnetism, simulation, hysteresis loop, blended learning, remote labs.

1   Introduction

Laboratory based courses together with hands-on experimentation have a vital role in engineering and science education [1]. In recent years, educational researchers consider the significance of adding ICT enabled learning in science education to facilitate experimental studies beyond limits of a classroom [2]. The prominent usage of virtual laboratories in education has been reported to provide new insights to support education [3], [4]. Blended learning approch of implemeting virtual lab courses together with physical experimentations have became a most popular scenario in most of the university sectors [5]. Government is also taking up initiatives to bring virtual lab

based education as an e-learning platform for augmenting the current education strategies [6], [7].

Many universities and research institutes have already launched virtual and remote laboratories on the web, which are accessible to users around the world. 'Netlabs' developed by University of South Australia (http://netlab.unisa.edu.au/), 'iCampus iLabs' from Massachusetts Institute of Technology (http://icampus.mit.edu/projects/ilabs/),and 'Remotely controlled lab' from the Palacký University of Olomouc (http://ictphysics.upol.cz/remotelab/) are good examples of remote laboratories that allow users to conduct experiments remotely on real laboratory equipment. Virtual Amrita Laboratories Universilizing Education (VALUE) have been implemented as part of Ministry of Human Resource Department's (MHRD) ICT initiative, in collaboration with several Indian Institutes of Technology (IITs) and other universities in India. The project focused on reproducing real lab experiments to a virtual environment using techniques such as animation, simulation and remotely controlled experiments (http://vlab.co.in/) . Animations graphically deliver the wet lab procedures with a close semblance to physical experimentations. Simulations were designed with mathematical models for reconstructing real datasets. Remote labs provides users with access to real lab equipment, from a distant location, through internet [8]. Access to experiments were based on user registration that have been employed to track statisctics of experiment usage. VLCAP platform was used for implementing and deploying virtual labs [9]. Such online classroom instructional materials were used as supplementary laboratory courses and as interactive textbooks apart from scheduled classroom hours [10]. Several pedagogical studies were carried among university students and professors to analyze the role of virtual and remote laboratories in augmenting laboratory education[11]. Studies suggested the use of remote laboratories in augmenting laboratory education of undergraduate and postgraduate students in universities . Role of remotely controlled experiments as a flexible learning and teaching platform were analyzed using remotely controlled light microscope experiment as a learning exercise[12]. Studies also showed the implementation strategies of remote triggered photovoltaic solar cell experiment and the fundamental characteristics of photovoltaic solar cells, a basic undergraduate experiment in science and engineering course [13].

In this paper, we have discussed about the remotely controlled hysteresis loop tracer, a physical experiment used to determine various magnetic parameters commonly performed in physics laboratories of most engineering courses that was designed and deployed as a virtual laboratory experiment. We also implemented a hysteresis loop tracer simulator for improving pedagogical experience in learning and teaching. The objective was to virtualize magnetic tracer and establish a remote tool for teaching and learning magnetic hysteresis process, later analyzing the impact of such online educational tools amongst student users.

1.2   Overview of Hysteresis Loop Tracer Experiment

When a magnetic material is subjected to a cycle of magnetization, the graph intensity

of magnetization (M) vs. magnetizing field (H) gives a closed curve called M-H loop. Magnetization intensity M does not become zero when magnetizing field H is reduced to zero. Thus the intensity of magnetization M at every stage lags behind the applied field H. This property is called magnetic hysteresis. The M-H loop is called hysteresis loop. The shape and area of the loop are different for different materials [14]. The phenomenon of magnetic hysteresis includes identifying the magnetic properties   such as coercivity, retentivity, saturation magnetization,   and thereby establishing the identity of the material itself (Fig.1). The presence of multiple components in the same sample can be recognized by distinctive changes in the slope of the hysteresis curves as a function of applied field [15], [16].
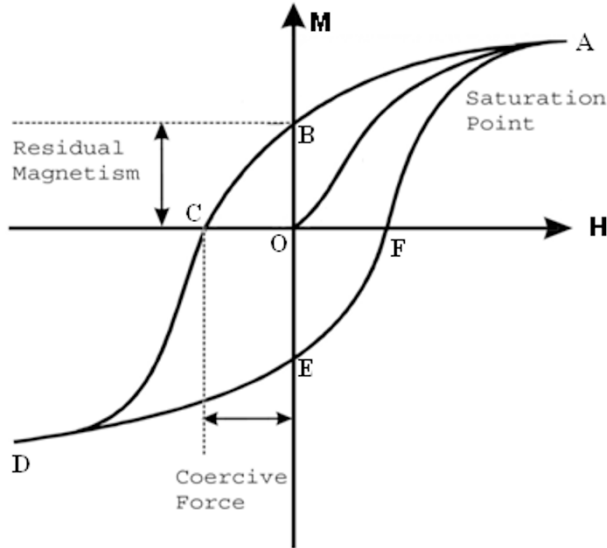

Fig.1. Magnetic hysteresis loop showing coercive force OC, residual magnetism OB, saturation point A

Even though equipment is commonly available in laboratories, access to laboratory usage hours restricts student's practice on such equipment. Also the equipment was costly and needs to be maintained. In situations, where universities were not well localized to suit requirements of laboratory education, virtual and remotye experimentations were implemented as a supplementary learning environment   to train students "anytime-anywhere" and for repeating trials in order to facilitate learning based on trial-and-error, which   has   been   known   to   increase learning interest and motivation of students [6].

2   Materials and Methods

2.1   Mathematical Modeling of Hysteresis loop tracer

As a part of modeling hysteresis loop tracer, a HLT Simulator was developed in MATLAB (Mathworks, USA) that used mathematical models with a series of instructions, which facilitates user interaction. The Jiles - Atherton Model [17] was chosen for simulating the magnetic nature of the material.   Magnetic hysteresis was recorded from   the following equations (1), (2) and (3).

$$\frac{dM_{irr}}{dH} \quad = \quad \frac{M_{an}-M_{irr}}{d \times k-\alpha \times (M_{an-M_{irr}})} \tag{1}$$

$$\frac{dM_{rev}}{dH} \quad = \quad c \times \left(\frac{dM_{an}}{dH} - \frac{dM_{irr}}{dH} \right) \tag{2}$$

$$M = M_{rev} + M_{irr}$$

(3)

Where, M_{rev} is the reversible magnetization, M_{irr} - irreversible magnetization, M_{an} - anhysteric magnetizations, c- Reversibility coefficient, k - Coercivity parameter, α - Domain Anisotropy parameter. Simulator provided the user a better user interface experience and the possibility to observe the variations in the plot as a level of interpretation of material characteristics in a broader sense.   To   observe changes in   magnetic properties   of materials, soft and hard magnets were used for characterizing hysteresis curve.

2.2   Architecture of Remote labs

To provide online access, actual implementation   of the remotely controlled   hardware setup of the HLT was done. The control setup for the HLT tracer was connected to a Data Acquisition Device (DAQ), which served as the interface between the server and the device [11]. Effective modeling of control was done by programming access to the DAQ through a   computer. Server hardware was optimized to handle a large number of requests. All experimental setup[18] remained connected to the server. The server received the requests from online users and processed commands to equipment hardware through DAQ and the data from the equipment was sent back to the user. The server communicated with the client through a service-broker. On completion of an experiment, the server notifies the user through a service broker when the results became available. The setup used a web server to communicate between a data acquisition module and the device which was to be remotely triggered. Data traffic and connection to the clients were handled by an apache server[12]. In order to avoid hardware damage, client access was delimited to pre-selected controls necessary to perform the experiment (Fig.2).
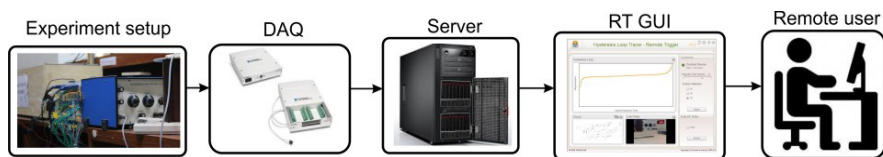

Fig.2.   Block Diagram of Remotely Controlled HLT Setup.

2.3 Remote Controlled Hysteresis Loop Tracer - Hardware setup

The hardware circuit consists of a sweep unit, integrator and differentiator unit for obtaining the voltages proportional to the input magnetic field (H), magnetization (M) and its first and second-order derivatives corresponding to the speed and phase-change of magnetization . Magnetic field was obtained with a solenoid driven on AC. Magnetic field was calibrated with a Hall Probe for uniformity and the field was calculated via AC current passing through the solenoid. A small resistance in series with the solenoid serves the purpose of taking a signal e_1 corresponding to H. The signal e_2 (corresponding to $\frac{dM}{dt}$)was taken from the pick-up coil placed at the centre of the solenoid containing the sample andwas integrated and phase-corrected. This signal was then subtracted from the reference signal e_1 and amplified to give the signal corresponding to M. The e_1 signal was also subtracted from e_3 maintaining the correct ratio (to account for demagnetization and area ratio) and amplified to give signal corresponding to H. e_2 was also passed through the differentiator for getting signal corresponding to $\frac{d^2M}{dt^2}$ which was used for phase identification. The solenoid and pickup coil arrangement had a maximum current specification of 4A. Also, 10-turn helipots were used as variable resistors for initial calibration of the experiment. Varying amplitudes for the input magnetic field were obtained from a 10-tap transformer with output voltages from 9.6 V to 126 V and a maximum current rating of 4A. The operational amplifier (op-amp) used were standard 741 op-amp integrated chips (ICs).

2.4 Theory of operation of remotely controlled Hysteresis Loop Tracer

Students could access experiment Graphical User Interface (GUI) through a web browser. The GUI consisted of controls for performing the remote triggered hysteresis loop which included a slider to choose the input magnetic field values and a set of radio buttons to choose the plot type to be displayed. User sent data and access information to the remote server while triggering the experiment remotely. The control signals from the client machine were transmitted to the remote server in XML format. For interfacing the hardware to the server, DAQ Module 6221 USB M-Series was used. Inputs to the hardware circuit were obtained from the server from the DAQ Virtual Instrument [16].The digital inputs were employed for selecting the amplitude of the applied magnetic field. The user was able to switch the input amplitude of the applied magnetic field. Switching the applied magnetic field was done by establishing switching between the taps of the transformer in a remote manner. Using this structure the remote user could change the input magnetic field by using the GUI-based slider. The relay structure consisted of a set of 10 relays driven by the relay driver ULN2803A. The analog voltage outputs coming from the hardware corresponding to the applied magnetic field (H) and the magnetization of the sample (M) was relayed to the server and then sent to

the user. User was able to see the M-H curve on the GUI (Fig.3).

Additionally, user could also switch between three outputs, M, $\frac{dM}{dt}$ and $\frac{d^2M}{dt^2}$. User could see the M-H plot, $\frac{d\,M}{dt}$-H plot or the $\frac{d^2M}{dt^2}$-H plot according to their choice on the graph plot element placed on the GUI. The remotely-controlled magnetic hysteris loop experiment is openly available via http://vlab.amrita.edu/index.php?sub=1&brch=195&sim=800&cnt=1.

2.5   Usage and Usability analysis via Field trials

To estimate user behavior and usability, several field trials were conducted in different universities in India to undergraduate engineering students. After providing basic instructions on how to use virtual and remote labs, each of the 200 participants were allowed to perform remote experiments independently. Among 200 students, 50 students were specifically allowed to study Magnetic Material Characterization via Hystersis.   After completing the lab exercise, a questionnaire-based direct feedback was collected from participants to analyze their learning experiences   using virtual lab. The questions for analysis were as follows:

1.   Virtual lab techniques such as animation, simulation and remote labs helped in understanding experiment concepts necessary for using it in a physical laboratory.
2.   Would you prefer including simulations to augment laboratory access in your studies?
3.   Do you agree that remote lab helps to provide students with a feel of real equipment?
4.   Would you support blended learning approach of using simulation and remote labs in their learning?

User's responses (yes/no) were used for assessment

3   Implementation

3.1   HLT Simulator Implementation

The coding of the Jiles - Atherton model HLT Simulator was done in two parts: coding of the hystplot function and linking of the function with a Graphical user interface (GUI) using MATLAB. A "hystplot" function accepted the inputs namely, relative permeability and five Jiles –Atherton parameters, which defined the nature of sample under observation. The amplitude of the alternating magnetic field applied was also given as an input to the function. Euler's Method   was used for calculating   the value of M for each value of input   H. Hysteresis plot created in the simulator GUI (Fig.3) We also recreated the simulator on Adobe Action Script for the web-based virtual lab.

3.2   Remotely Controlled Hysteresis Loop Tracer

The   hardware   circuit   modeled   in   PSpice   was   implemented   on hardware and

interfaced to the server-side computer using the DAQ 6221 Module. 9 digital inputs and two analog inputs of the DAQ Module were used. In this design, applied magnetic field was provided using a rotating "Dial" whereas output plot choice was enabled by "Knob". The hysteresis loop and the plots for the rate and phase of hysteresis were obtained in the server-side computer on the interface (Fig 4A,4B and 4C). The results, although in agreement with the actual experimental setup have showed minor differences due to errors and noise introduced during interfacing.
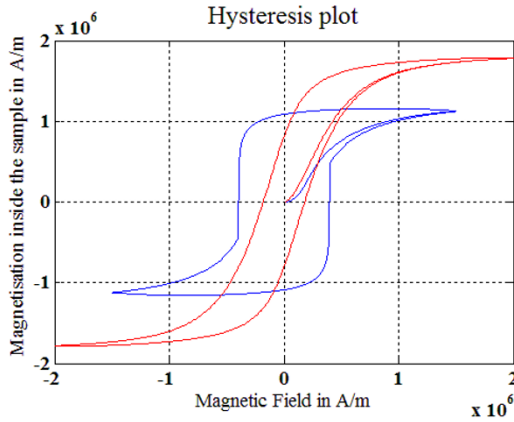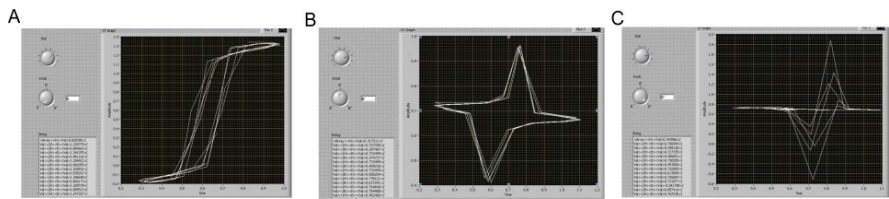

Fig 3. Simulated Hysteresis plots of two materials

Fig. 4 Snapshots showing the plots for A) Hysteresis Curve B) Speed and C) Phase of hysteresis

4 Results

4.1   Virtual Lab Simulator Augmented Student Access

Among the student participants, 84% of them indicated that virtual lab techniques such as animation, simulation and remote labs helped them in understanding experiment concepts necessary for using it in a physical laboratory. 90% of them preffered to include simulations in their learning to augment laboratory access (Fig.5, responses for feedback questions Q1 and Q2). Specific feedback from 50 undergraduate students who

have performed HLT experiment indicated all of them (100%) were able to reproduce
hysteresis plots and tesed their understanding about the basics of hysteresis and the
impact of varying different Jiles-Atherton parameters on the hysteresis loop of two
magnetic materials A and B,via the simulator platform without the help of an instructor.
Students were able to interpret the graphical analysis, as the thinner loop represents
material B and the thicker loop corresponds to material A. From the graph
obtained   in   GUI,   students were able to calculate saturation magnetization,
reversibility coefficient, coercivity parameter and domain anisotropy parameter.

4.2   Remote lab Enhanced Student's Laboratory Training Experience

Among the student participants, 82% agreed that remote lab helped them to provide
with a feel of real laboratory equipment. 88% indicated using blended learning approach
with simulation and remote labs in their studies (Fig.5, responses for feedback questions
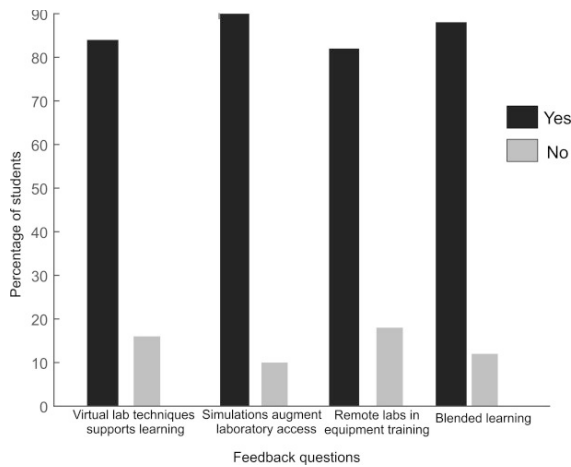Q3 and Q4).

Fig. 5. Role of virtual simulations and remote labs in education

Specific feedback collected from the study participants of HLT experiment   were
used   to   determine   the   adaptation   of remotely controlled labs as a lab
exercise in their learning process.

User responses (86%) indicated that the materials provided by the online labs are
easily adaptable tools for students   to   improve   their skills in laboratory
practices.Some of theparticipant commented (as is, from our feedback forms):"In our
college laboratory, we are sharing lab equipments   and performing the experiment as a
group. Virtual and remote lab setup helped me practicing the experiment
individually",   "Interesting   and   valuable platform!! If this is successfully
implemented in all the colleges, there will be definitely a change in the quality of
students passing out." "Although the remote lab didn't feel as real as the actual lab,

remote labs lets students practice the experiment many times and compare the results in order to have a more fundamental idea. "Overall analysis suggested the   usage   of online   laboratories   enhanced   laboratory education amongst student groups.

5 Discussion

The   implementation   of   HLT   devices   indicates   a possibility of interfacing expensive technologies for standard classroom   usage. Mathematical   simulation   allowed augmenting   conceptual   knowledge related   to   laboratory equipment and supported student practice time on devices beyond   classroom   hours. Having both simulators and remotely controlled devices allowed students to compare between noises generated during recordings to ideal mathematical reconstructions. Remote   triggering   of   the   HLT   experiment showed promising   results   towards   extending   such   setups   for   the study of ferrite materials. Student   feedback indicated   choices   of   including   remote experimentation as part of curriculum. Studies on virtual simulation and remote labs implicate the roles of online labs in reducing instructor-dependence thus promoting student-centered   learning   process. The implementation   of   the   HLT experiment   facilitated   the pedagogical   use   of   online   equipment   as   a learning platform for students with time or cost limited access to real world experiments. Common problems with remote setups were   connectivity   and   slot   availability problems.   ICT enabled   virtual   and   remote   labs   in   education   shows promising outlook given the trend of   student   and teacher usage as teaching and learning tools.

5 Conclusion

The implementation   of a remote triggering   of the HLT experiment   opens up new approaches   of   online   education and experimentation. The implementation of a remote triggered, portable HLT device opens up a new approach in ferrite   material testing   in which experiments   can be done onsite. Usage of remote labs as an additional classroom material for teaching skills also represents novel changes in engineering research. The emerging achievements of virtual and remote labs in creating online courses, is an area which is extending and thus needs a further research. Large-scaletests will be needed to analyze and provide the assessment. The virtual lab is free for use and can be accessed via http://vlab.amrita.edu

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