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# Designing and fabricating a stationary magnetic particle system for Non-destructive testing

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**Abstract:** The bench unit, also known as the stationary magnetic particle system or the wet horizontal system, has been designed and fabricated to incorporate both circular and longitudinal magnetization techniques. Its primary purpose is to test machine parts commonly used in various industries, including aviation, automotive, and railway. The system comprises several key components: a transformer, a current control unit, a parameter display and adjustment circuit, a head shot, a coil, and wet magnetic irrigation device. This system is in compliance with international standards and is ready for implementation in companies that require it.

**Keywords:** *ASTM, NDT, MT, Bench unit.*

## I. INTRODUCTION

Magnetic Particle Testing (MT) is a common nondestructive testing method used to inspect objects made of ferromagnetic materials in order to detect surface and near-surface discontinuities. To achieve the highest sensitivity during the testing process, the orientation of the magnetic field must be perpendicular to the discontinuities. In practice, the orientation of these discontinuities is random and depends on the shape, manufacturing process, and usage of the product. Therefore, to detect a maximum number of discontinuities most standards and testing procedures require magnetization in at least two directions, with the second magnetization direction perpendicular to the first one. Various magnetization techniques and equipment can be applied for each magnetization. Common equipment used in magnetic particle testing include yokes, prods, coils, and bench units. The bench unit, comprising both a head shot and a coil, can generate both longitudinal and circular magnetic fields on test objects such as aircraft engine components, automobiles, and railway vehicles, both during the initial manufacturing phase and periodic maintenance. The circular and longitudinal magnetization techniques in the bench unit are shown in figures 2 and 3.

The magnetic particle testing procedure typically includes the following steps: (1) surface preparation; (2) application of the magnetizing force, inducing magnetic field leakage to the surface in the presence of discontinuities; (3) application of magnetic particles to the test surface, where leaked magnetic fields attract and concentrate the particles, forming an indication that reveals the presence of a discontinuity; (4) observing, interpreting, and evaluating the results; and (5) demagnetization and post cleaning.

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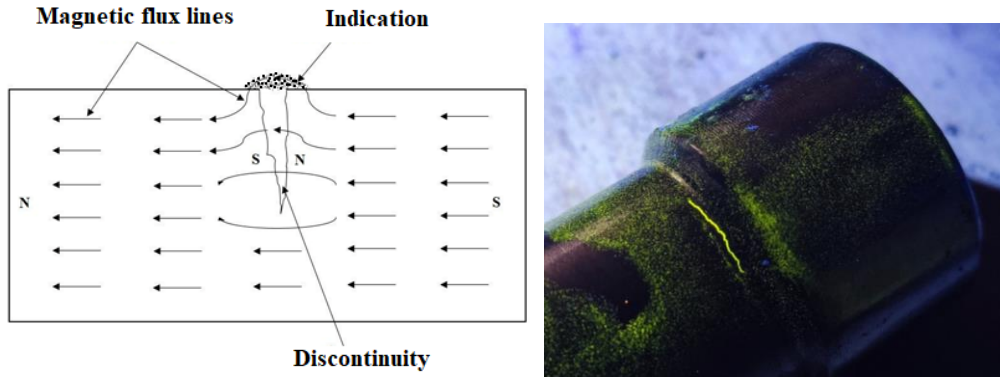



**Fig. 1.** MT principle and typical discontinuity

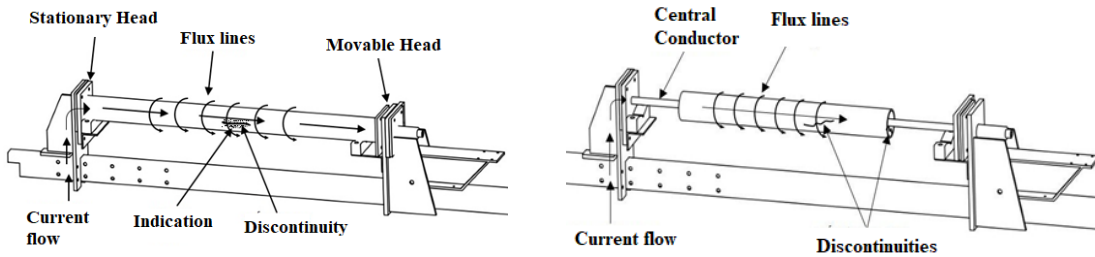



**Fig. 2.** The circular magnetization technique utilizes a head shot and a central conductor

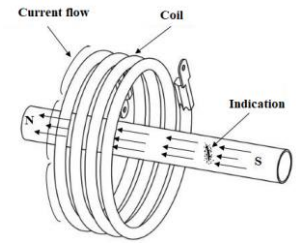



**Fig. 3.** The longitudinal magnetization technique utilizes coils

Currently in Vietnam, only a few companies in the precision mechanical manufacturing industry use this system, and most of them import it from abroad at extremely high prices. Furthermore, they face difficulties in repairing, maintaining, and calibrating the equipment. Therefore, the authors conducted research to design and fabrication a magnetic particle testing system (bench unit) that complies with ASTM E709 and ASTM E1444 standards. The primary goal of this endeavor is to enhance self-sufficiency in Vietnam and reduce dependence on foreign suppliers.

## II. DESIGNING AND FABRICATING AND ACHIEVED RESULTS

### A. Designing and fabricating

Through an extensive survey of the requirements for magnetic particle systems at various organizations in Vietnam, with a particular focus on the aviation industry and precision machinery manufacturing units, the authors have undertaken comprehensive research and synthesized relevant documents encompassing fundamental principles in the fields of electrical engineering, electronics, mechanics, and applicable standards. This effort

has enabled the development of the most suitable designs. Throughout the fabricating process, the system is continually assessed for suitability, and design parameters are optimized to ensure the production of a high-quality product that complies with ASTM standards.

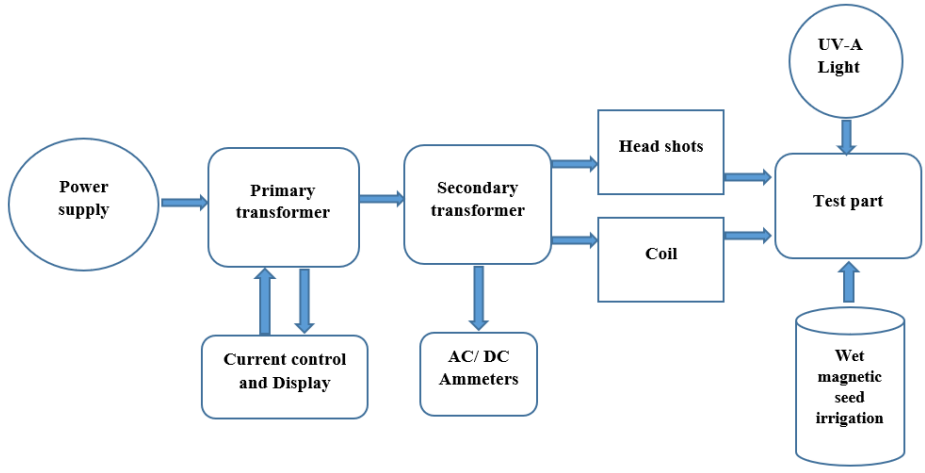



**Fig. 4.** Principle diagram of the Bench unit

From the basic principle diagram of the bench unit, each part has been successfully designed, fabricated, and assembled into the complete system by the authors. This system is evaluated for accuracy, stability and overall system performance according to ASTM E709 and ASTM E1444 standards. The specifications of the bench unit are as follows:

Power supply voltage: 200 V - 240 V

Maximum output current: 1500 A

Type of current: AC and HWDC

Frequency: 50 – 60 Hz

Duty cycle: 10% at maximum current output

Timed current energies: 0.5s and 0.4s

Ammeter: Digital

Overall dimensions of the system (length x width x height): 150 x 70 x 154 (cm)

Central conductor: Copper, OD x L: 2,5 cm x 100 cm

Maximum test part length: 100 cm

Maximum test part diameter: 125 mm for the direct magnetization and 60 mm for the in-direct magnetization

Maximum part weight: 100 kg

Magnetic coil with 4 turns, diameter 300 mm

The wet magnetic particle irrigation equipment includes an 18-liter tank with an automatic stirring unit

The UV lamp has a peak wavelength of 365 nm and an intensity on the test surface of at least 1000 µW/cm$^2$.

**The Parameters, design drawings and products of the bench unit are as follows:**

| **Parameters of the primary transformer** | **Parameters of the secondary transformer** |
|---|---|
| - Input voltage: 220 V | - Input voltage: 0 ÷ 250 V |
| - Output voltage: 0 ÷ 250 V | - Output voltage: 0 ÷ 7 V |
| - Frequency: 50 ÷ 60 Hz | - Output current: 0 ÷ 1500 A |
| - Number of turns: 250 | - Frequency: 50 ÷ 60 Hz |

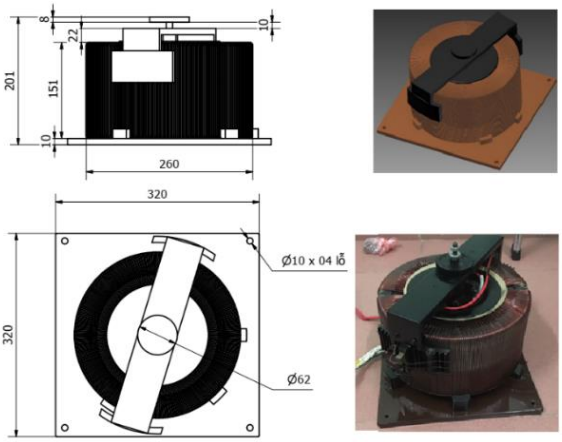



**Fig. 5.** Drawing design and product of the primary transformer

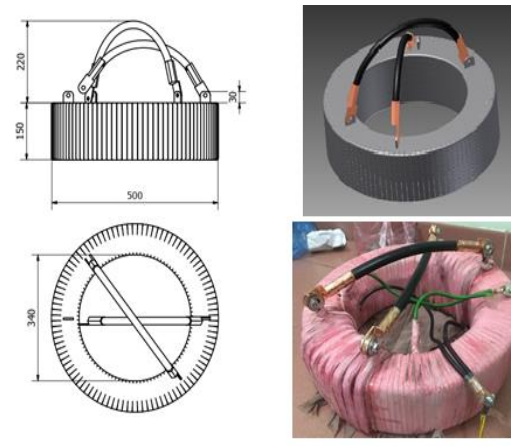



**Fig. 6.** Drawing design and product of the secondary transformer

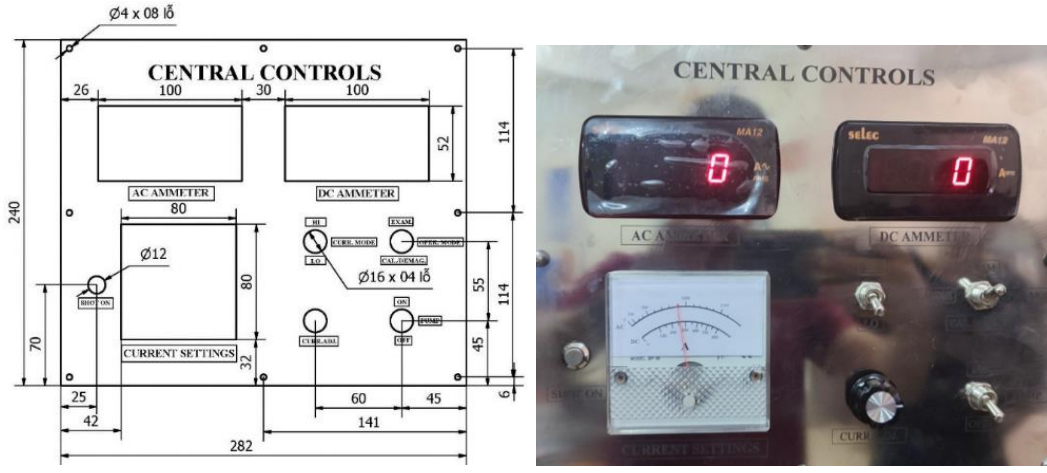



**Fig. 7.** Drawing design and product of the central controls

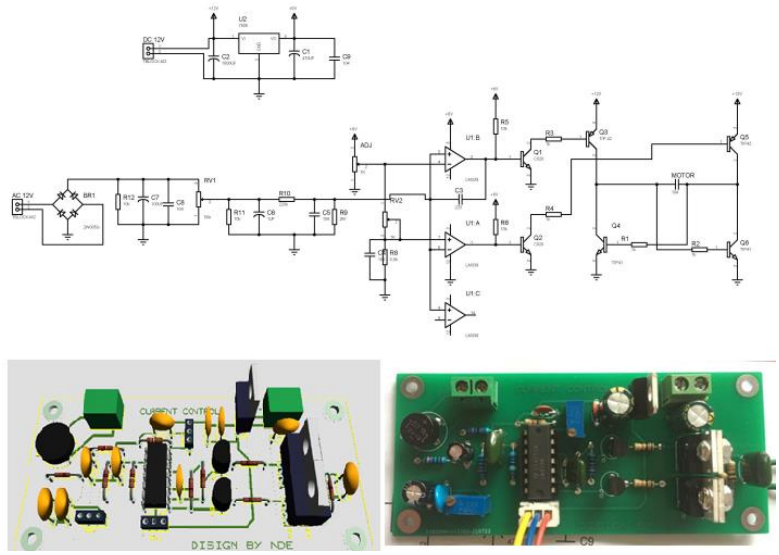



**Fig. 8.** Drawing design and product of the current control circuit

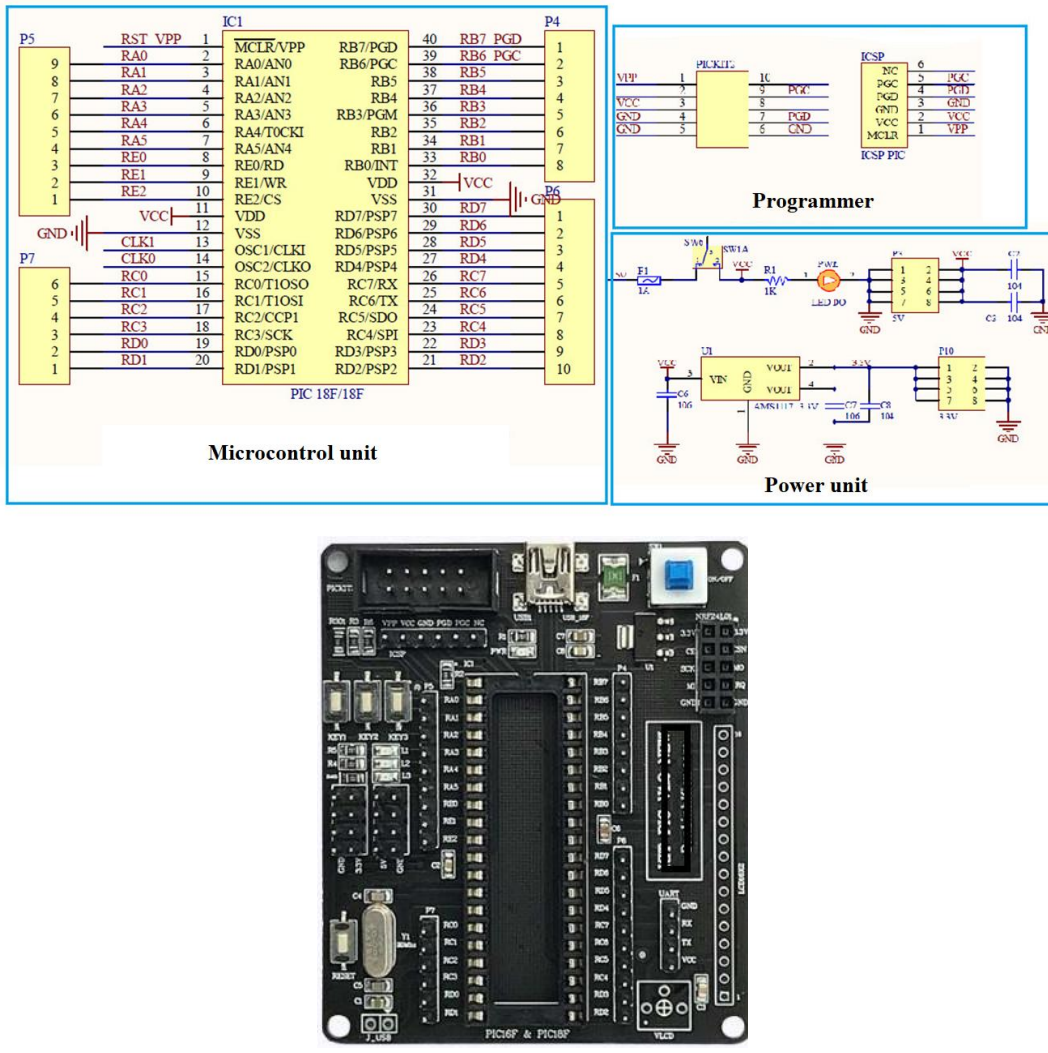



**Fig. 9.** Drawing design and product of the timer control circuit

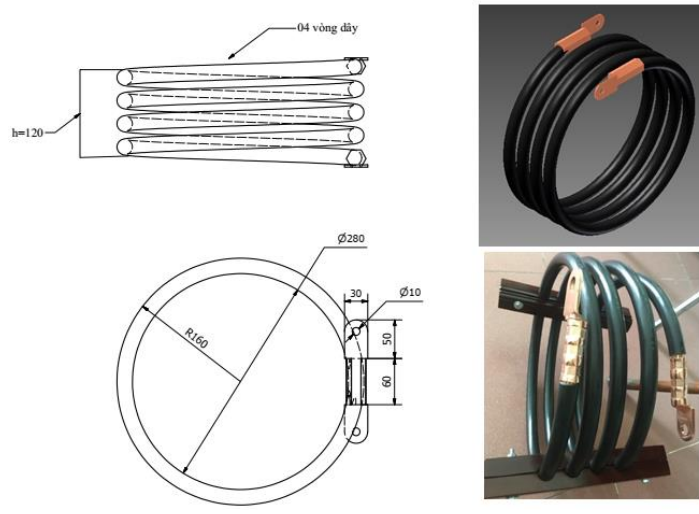



**Fig. 10.** Drawing design and product of the Magnetization coil

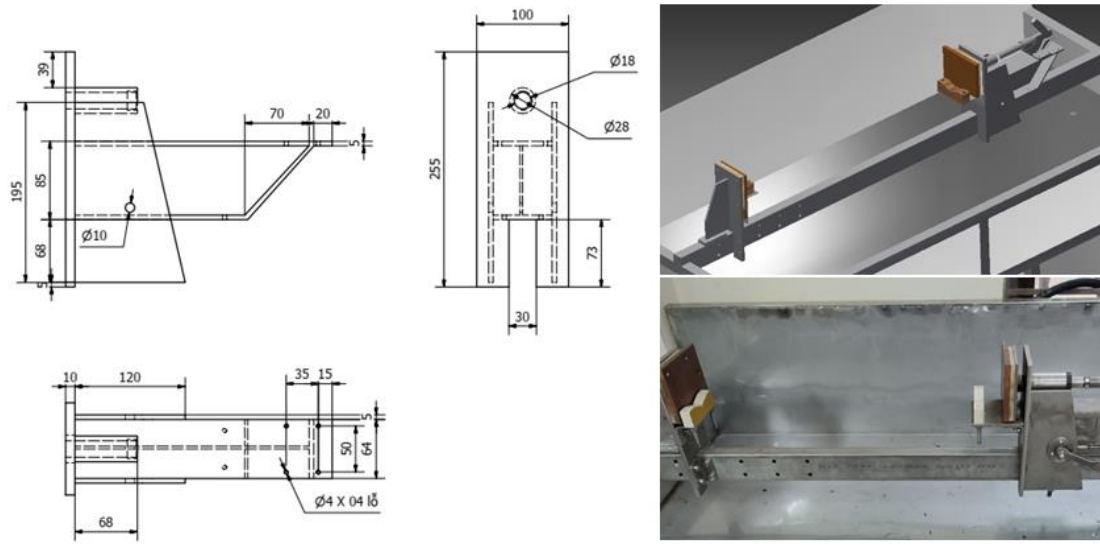



**Fig. 11.** Drawing design and product of the Head shot

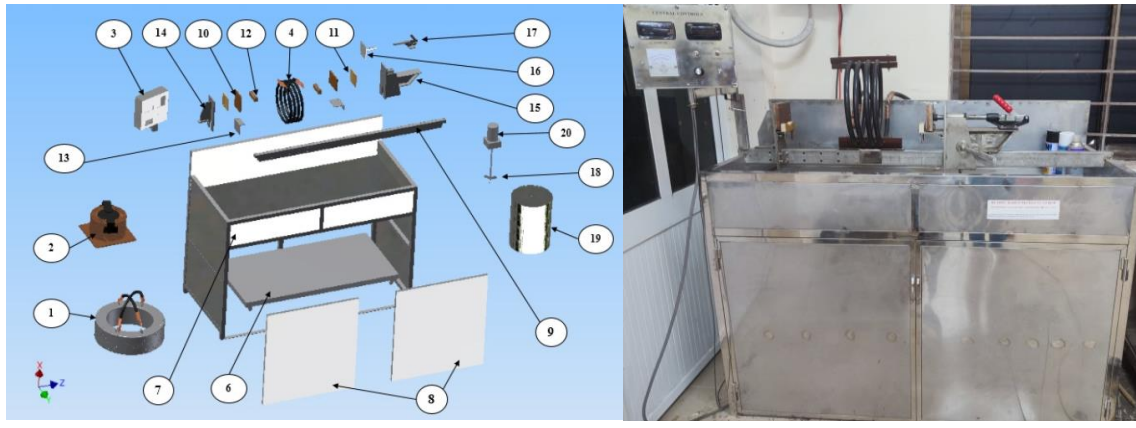



**Fig. 12.** The complete bench unit

### B. Evaluating the bench unit in accordance with ASTM E709 and E1444 standards [1] [2]

#### *1. Evaluating the accuracy and stability*

The accuracy and stability of the ammeter in the bench unit are evaluated. This assessment includes the measurement of the system's output current by connecting a shunt resistor meter in series with the headshot and coil, respectively. Subsequently, the current flow is measured and compared to the current value displayed on the shunt resistor meter. In accordance with ASTM E709 and E1444 standards, the deviation between these current values must not exceed 10% or 50A, whichever is greater. This evaluation criterion is applicable to both alternating current (AC) and half-wave rectified direct current (HWDC) equipment systems.

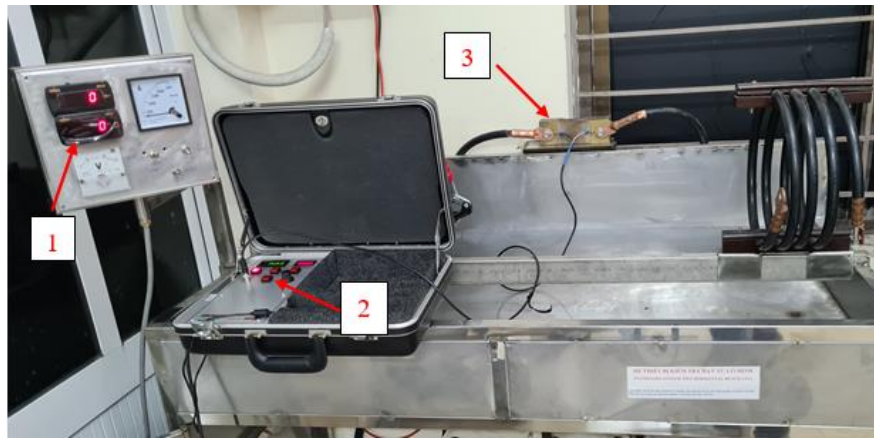



**Fig. 13.** AMMETER ACCURACY

*Note:* 1. Equipment ammeter 2. Shunt KIT ammeter 3. Shunt resistor

The evaluation is performed with randomly selected current flow values evenly distributed in the range from 0 to 1500 A of the bench unit. To ensure stability, assessments are performed multiple times a day and over multiple days. As a result, the current values displayed on the device and on the shunt resistor meter are within the allowable range of ASTM E709 and ASTM E1444 standards.

### *2. Checking for internal short circuit*

To ensure the system operates safely without electric leakage, checking for internal short circuit before use is necessary. The test is carried out by applying a maximum current flow of 1500 A to the clamping head assembly without any conductors between. The current meter must be at 0 A. If the meter displays any current value, it is a sign of an internal short circuit and the system must be repaired before use.

Test results of the bench unit show that when no conductor is placed between the two clamps and generates the maximum current of 1500 A, the current meter shows 0 A. Thus, the system operates well with no signs of internal short circuit.

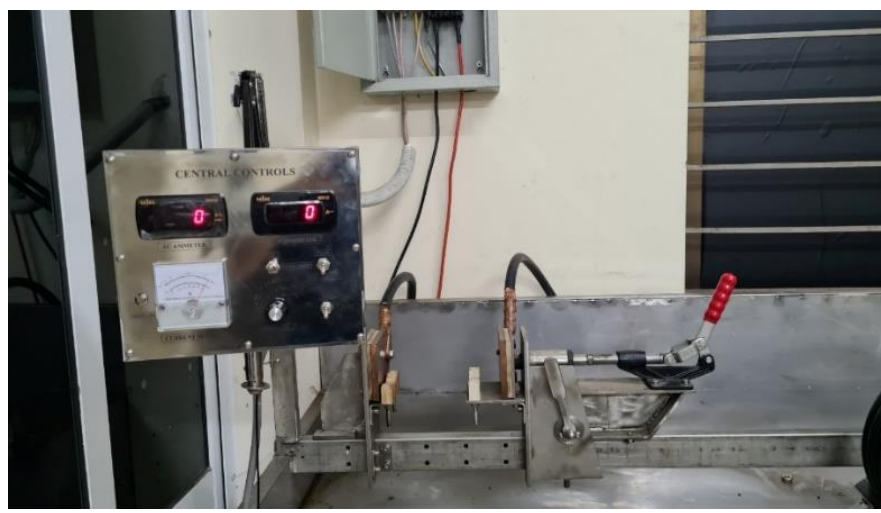



**Fig. 14.** Internal short circuit check

### *3. Evaluating the overall performance and sensitivity*

The system underwent an evaluation for both overall performance and sensitivity utilizing the Ketos AS 5282 ring. The evaluation employed the circular magnetization technique through the central conductor with a current of 500 A using HWDC, and utilized visible and fluorescent wet magnetic particle that conform to ASTM E709 and E1444 standards. The results of the equipment system's assessment demonstrate that the magnetic particle indications for three drill holes at a current level of 500 A meet the standard requirements.

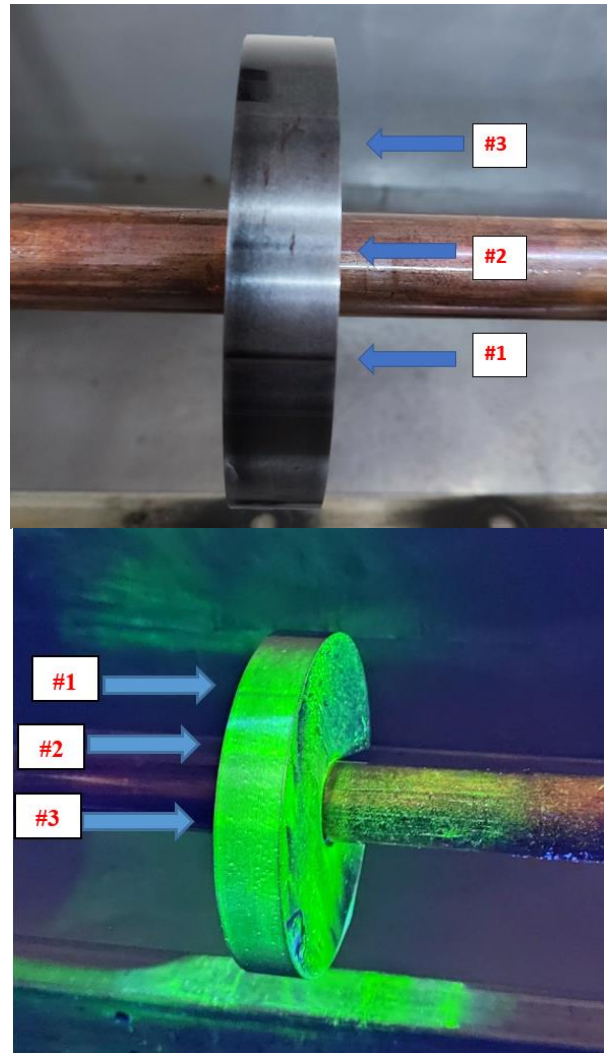
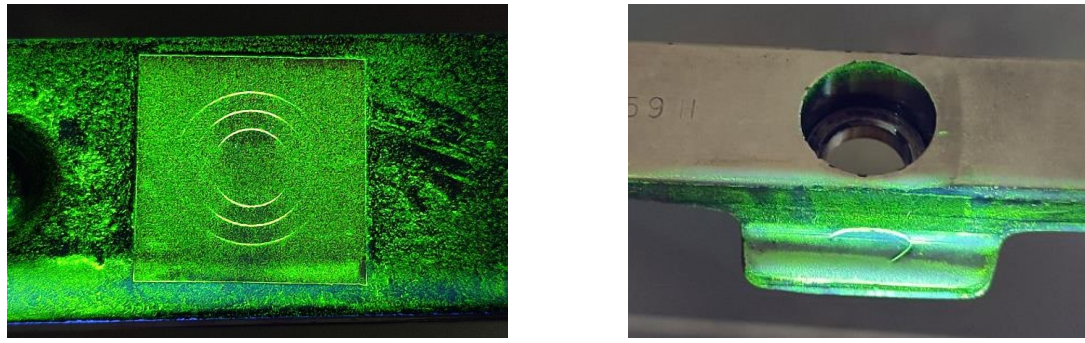



**Fig. 15.** Indications when tested on Ketos AS5282 ring

### C. Applying the bench unit to actual products

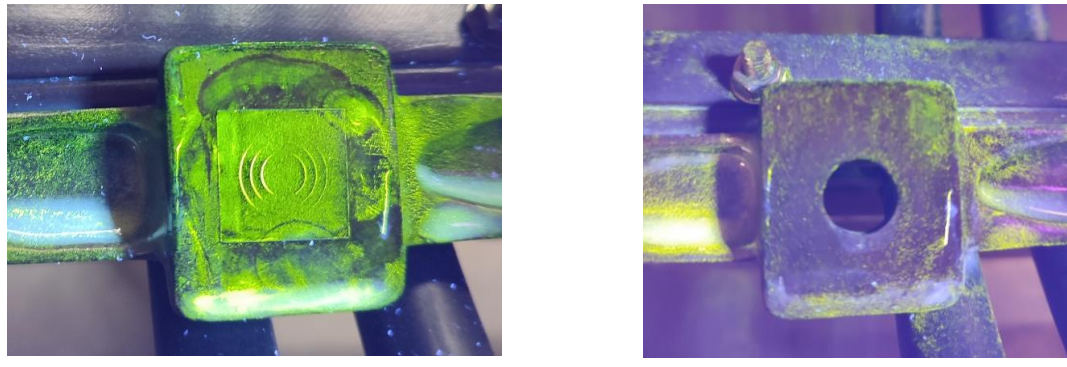
After undergoing assessments for stability and accuracy, the system is employed to inspect various cast and wrought machine parts. To thoroughly examine the entire component for both longitudinal and transverse discontinuities, it becomes essential to utilize both circular (head shot) and longitudinal (coil) magnetization techniques. Depending on the dimensions of the test object, the magnetizing current can range from 500A to 1000A. Before each test, the

adequacy of the magnetizing current strength is confirmed using a shim magnetic field indicator. The following image displays indication of cracks detected on a test object:



a) Indication on Shim's surface b) Crack indication

**Fig. 16.** Test results using the circular magnetization technique



a) Indication on Shim's surface b) Crack indication

**Fig. 17.** Test results using longitudinal magnetization technique

### D. Discussion

The Bench unit has been successfully designed, fabricated, evaluated and applicated on some products, yielding promising initial results. Grounded in mastery of the techniques, the testing procedures related to the equipment align with international standards. The outcomes of this research are expected to be widely applicable to various entities with diverse needs, ranging from direct fabricating applications to accompanying services such as maintenance, repair, calibration, and training for NDT personnel.

However, this system represents its initial version, meeting the basic testing specifications outlined in ASTM standards. Future iterations must undergo further improvements and upgrades to cater to actual user requirements, enhancing convenience. These enhancements may include:

- Enhancing the current parameter display unit to retain the maximum magnetizing current value.

- Implementing a control button-based switching mechanism between AC and HWDC currents, eliminating the need for manual conversion.

- Developing specialized pre-programmed software or AI tools to automate the testing process, as well as the analysis and evaluation of results.

## III. CONCLUSIONS

The bench unit has been fully designed and fabricated with a maximum magnetizing current of 1500A. This includes components such as the primary transformer, secondary transformer, current control, time settings, coil, and head shot. The Bench unit undergoes calibration for the following aspects: ammeter accuracy, timer accuracy, internal short circuit check, overall performance, and sensitivity, all in accordance with the requirements specified in ASTM E709 and E1444 standards. This calibration process aids us in mastering the technology, preparing for technology transfer for practical applications, facilitating localization of features, and reducing reliance on foreign factors. As a result, it leads to reduced product costs and enhanced competitiveness in the market.

## REFERENCE

[1]. ASTM E 709-21: Standard Guide for Magnetic Particle Testing, paragraph 20.3.

[2]. ASTM E 1444-22a: Standard Practice for Magnetic Particle Testing, paragraph 7.4;