**Quick Guidance for the Automated Triple Pulse Test Platform**

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# Summary

This guidance is specifically designed for the Automated Triple Pulse Test developed by the University of Bristol and Frenetic and is written by Mr Binyu Cui and Dr Jun Wang from the University of Bristol. Please email [bc16461@bristol.ac.uk](mailto:bc16461@bristol.ac.uk) if there’s any issue or concern.

The Triple Pulse Test is a method developed by the University of Bristol whose goal is to characterize the losses of a given ferromagnetic core under different testing conditions. In order to enhance its capabilities, a partnership between Frenetic and the University of Bristol has been established. The present document provides the users with a quick start and understanding of the Automated Triple Pulse Test Platform (ATPT). Detailed definitions and ground principles can be seen in the definition document which will be provided in the future.

# Triple Pulse Test Principle

The goal of TPT is to apply limited pulses to reach the desired B-H loop and avoid further unnecessary operation. The advantages of this approach are listed below:

1, It does not require a dc power supply with the capacity of supplying a large continuous current. As this is a relatively fast and short transition (e.g., < 200 μs), the current required in this process is mainly drawn from the dc-link capacitors.

2, A significant temperature rise is avoided due to the little heat generated from this process.

3, In the case where the current is measured by current probes, the dc current–time product I·t (in A·µs) in the process must not exceed the allowable range so that they would not saturate (reach nonlinear operation region).

The process of the TPT approach is illustrated in Figure 1. In **stage 1**, an initial pulse is applied to the inductor to build up the dc-bias condition. If zero dc-bias is required, then make T1 = T2A. If positive dc-bias is required, then make T1>T2A. The negative dc-bias condition is similar to the positive dc-bias condition which would result in almost exactly the same core loss so the negative condition is not considered here.

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| A picture containing diagram, line, plot, parallel  Description automatically generated |

Figure 1. Four operation stages for the Tripe Pulse Test.

In **stage 2**, Several cycles with desired voltage and frequency are applied to force the B-H trajectory of the inductor into a steady state. From the experiment experience in the UoB, two full cycles in stage 2 (N\_cycle = 4 in the program) are enough for the fundamental testing. Adjustments in cycles can be made depending on the practical situation. In **stage 3**, The desired cycle is captured and measuredby the program and in **stage 4**, the power devices are all turned OFF, and the energy stored in the inductor releases through the free-wheeling diodes, which leads to the current dropping back to zero at the end of this process. It should be noted here that for most testing, in order for the inductor could fully magnetize and demagnetize, the duty cycle should be 50% which means the T2A = T2B. The positive and negative voltage amplitude should also be the same. These two points are the main reason that could result in unwanted bias and unstable waveform under large signals.

# Hardware Architecture

The main hardware elements of the setup are displayed in Figure 2. The blue parts are already implemented in the platform while further improvement is indicated in the purple parts.

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Figure 2. Block diagram of the hardware architecture

The basic function of each elements is listed here:

1. Computer: centralizes the control of the different hardware units. It also manages the acquisition of the core losses data.
2. Power Supplies: they provide the required excitation voltage for the TPT test. They can be controlled from the computer to enable test automation.
3. Capacitor Bank: due to the very short duration of the TPT test, an appropriately rated capacitor bank is enough to maintain the required voltage levels during the whole operation.
4. Discharge Protection: used to guarantee the safety of the operator when the equipment is not in use. It ensures that the capacitor bank does not remain charged.
5. Power Stage: custom-built half bridge used to stimulate the cores under test.
6. Microcontroller: required due to the significant number of digital signals involved in the setup, and to the real-time constraints imposed by the test method. Teensy 4.1 is used as microcontroller in this design version.
7. Oscilloscope: used to acquire the relevant electrical signals for the TPT test. It is managed by the computer so that the acquisition process can be automated. Picoscope 3406d is used as a programmable oscilioscope in this design version
8. Voltage and current probes: connected to the oscilloscope, they are used to sense the relevant voltages and currents.
9. Vector Network Analyzer: to characterize components in terms of their impedance over a certain frequency range.
10. Temperature Control System: required to test the magnetic components under different temperatures.
11. Electronic Load: to allow transformers to operate in nominal conditions.

The main structure of the platform is the votlage excitation circuit which supported by a modified half-bridge design from the UoB. The circuit schematic is shown in Figure 3 and the actual testbed layout is shown in Figure 4.

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Figure 3. Modified half-bridge excitation schematic for the TPT

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Figure 4. Actualy testbed layout for the TPT

The general design specification for the excitation circuit is listed in Table I and the usage of each component will be briefly introduced in the following paragraph.

Table I Components in the Automated TPT Platform

|  |  |  |
| --- | --- | --- |
| Power supply units | PS 9750-04 2U | 750V, 4A |
| Discharging resistor | MP925-33.0K | 33 kΩ |
| Electrolytic capacitor | ALA7DA561EE500 | 560uF |
| Ceramic capacitor | MKP1848H65050JY5 | 50uF |
| MOSFET | C3M0032120D | 1200V, 63A |

The two programmable voltage supplies, V1 and V2, can generate and alter the voltage according to the received signals from the computer. Since it’s essential to keep the positive and negative voltage amplitude consistent, two separate power sources are essential to compensate for the body diode voltage drop. More detailed calculations can be found in [1]. Two 33kΩ, 25W resistors, R1 and R2, are connected parallel to C1 and C2 respectively for the purpose of discharging after the power is off. The time constant that implemented in the current design is 132s. This value can be improved by decreasing the capacitance and resistance value according to future design specifications.

C1 and C2 are two sets of parallel-connected capacitor groups, each of them consists four electrolytic capacitors and one ceramic capacitor with a total capacitance of 1.05mF. This reservoir capacitor group could ensure a stable voltage output with a 0.75% decrease in voltage when supporting the TPT test working under testing conditions with minimum frequency shown in Table II. It should be noted that the total capacitance may be decreased to 400uF for a higher power density. Please check the BOM for more detailed information.

Table II PCB Design Specification

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| --- | --- |
| Max voltage | ± 400V |
| Max current | 60A (Depending on MOSFET) |
| Max frequency | 500 kHz (recommended) |
| Min frequency | 5kHz (recommended) |

Two SiC MOSFETs c3m0032120d from Wolfspeed and two gate drivers from the UoB are used for the switching stage. Since the TPT is a discontinuous measuring method which only needs approximately 10 switching cycles for each test, heatsinks or other heat dissipation method is not necessary. However, the ATP support testing a group of variables continuously (with a 2s program set-up time between each test) which could potentially lead to a high junction temperature. Thus, a heatsink may be added to the next version of the TPT PCB. Please check the BOM for more detailed information.

Three probes are expected in the testing environment, two voltage probes connected to the primary and second winding respectively, and a current probe that measures the primary winding. The probes used in the UoB are shown in Table 3.

Table III Probes used in Automated TPT Platform

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| Primary voltage probe | Picoscope TA041 |
| Secondary voltage probe | Picoscope TA375 |
| Primary current probe | Keysight N2783B |

# Hardware limitation

**1, Voltage limitation**: The PSUs chosen for this platform are two Elektro-Automatik PS 9750-04. According to the manual, the restriction of the PSUs is maximum positive terminal to protective earth (PE): +1150 V, Maximum negative terminal to protective earth (PE): ±400 V. Due to this restriction, the dc-link voltage is limited to 800V which is also the limitation voltage for the PCB designed by the University of Bristol.

**2, Current limitation:** The current limitation for the PSUs is 4A. However, this limitation does not apply to the current rating for the inductor under-tested. The current that flows through the inductor is mainly supported by the reservoir capacitor. The limitation for the testing current mainly depends on the saturation current of the inductor under-tested.

**3, Frequency limitation:** Frequency limitation is not considered at the moment since the purpose of the ATPT design is not focused on the performance of the inductor under high frequency. The recommended testing frequency is 5kHz to 500kHz. It’s possible to increase or decrease the switching frequency when the inductor characteristics and the influence of parasitic components are carefully considered.

# Before starting test

1. Please make sure the solder the main PCB and Teensy controlling PCB correctly according to the bill of material supplied by the University of Bristol (UoB).
2. Install the gate driver properly and connect the coupling wire between the gate driver and the Teensy control board (detailed procedure can be found in the gate driver manual).
3. Set the programmable power supply units and the oscilioscope properly according to their manual. Please download the EA power control application on your PC for the PSUs. For the oscilioscope, please download the PC Picoscope software that fits your model type (2000 or 3000 series).
4. The Arduino signal-generating program should be uploaded to the Teensy before starting the program. Please download the suitable application from the Teensy website.
5. After opening the program, please check the main.py to install all the needed libraries and packages from the ‘import’ part.
6. After powering up the PSUs, please use the application to enable the remote control for both PSUs.

# Software Functions

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Figure 5. Flow chart of the software architecture

Three main function of the main TPT program is depicted in Figure 5. It shows the procedure and the online/offline status when operating each function. Some additional functions can be found and already implemented in the program package however these functions are not introduced or used in this version. A brief description of each function is given below.

## 1, Test point loading and verification

Before starting the point-to-point test, three variables in each of the TPT data points in this group are needed. These variables are initially set in the program structure but it’s easy to alter the variable type base on the structure. I\_delta is the current difference for half switching cycle, I\_0 is the dc-bias condition and f is the switching frequency. It should be noted here that despite the dc-bias condition can be either positive or negative. For the core loss measurement, there’s no difference since the positive & negative biased waveforms will be symmetric. The UoB recommend the positive biased condition as this will not change the structure of the testing waveform. Three arrays corresponding to these three variables can be found in the tpt\_automation/TPT\_group\_variables\_setup function. By inputting the values in these arrays before starting the program, it will combine every element from three arrays and you could acquire a two-level TPT test point array with three variables in one element.

The next step is to load and verify the feasibility of the test point variables. By choosing the “*12 - Input TPT variable group*” on the main menu as shown in Figure 6 and following the instruction, the variable that was manually typed into the program earlier will be locked and loaded. It should be noted here that if any set of variables exceeds the limitation, the function will point out the error value and location. The correction for the array needs to be made when the program is offline. After finishing inputting the variables of all the data points, you could run the tpt\_main.py to initialize the testing.

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Figure 6. Screenshot of the menu in the main program

## 2, Large-signal inductance test

The large-signal inductance and the inductor saturation parameters are needed before starting any testing. Choose “*5 - Perform a guided inductance test*” in the main menu to start the large signal inductance measuring. By giving the program a small-signal inductance value, the programme could provide a recommended excitation voltage and slowly increase the time period of the switch-on time in a while loop to push the inductor gradually to saturation. After an abnormal current increase is detected, the program will save all the parameters and plots in the /Output file with the testing time record. The large-signal inductance and saturation current will be saved as global variables.

## 3, Automated TPT test & voltage feedback loop

After acquiring the saturation parameters and loading the group test points, “*9 - Perform a guided TPT test*” in the main menu is ready to be used. If you choose the load the group test points, you won’t be needed to do any further operations. However, you will need to input all the TPT parameters manually if you want to test a single test point. Both functions (single test & point-to-point test) has been implemented the voltage detecting feedback loop to keep the consistance of the positive and negative voltage amplitude. After each testing period, the program will extract the voltage data from the oscilloscope and detect if the voltage difference is larger than 0.3V. The voltage will be corrected by 0.1V each time and reran if the difference exceeds the limitation. Under the point-to-point testing environment, the program will automatically iterate all the test points and save the TPT parameters and measurement in the /Output file with index. It should be noted that the iteration caused by the over-limitation rerun will not be recorded in either the program or the output file.

## 4, Data processing

“*11- Process existing TPT test*” in the main menu allows us to process the result data from TPT when the hardware is offline. The program will boost up much faster when all the hardware is disconnected from the computer. By using this function, the electrical and magnetic waveform can be plotted using the chosen dataframe. The core loss can also be calculated. Examples of this function is shown in Figure 7.

# Reference

[1]J. Wang, K. J. Dagan, X. Yuan, W. Wang and P. H. Mellor, "A Practical Approach for Core Loss Estimation of a High-Current Gapped Inductor in PWM Converters with a User-Friendly Loss Map," in IEEE Transactions on Power Electronics, vol. 34, no. 6, pp. 5697-5710, June 2019.