The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2021

Volume 16, Pages 87-97

IConTES 2021: International Conference on Technology, Engineering and Science

Adaptable Fiber Laser Control Unit

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Abstract: Today fiber laser is widely used due to their performances and flexibility. They replace old types of lasers in the industrial machines. To develop a family of laser machines it is the need of having standard laser source that could efficiently be used and replaced in the equipment, independently of the laser source or types of lasers. This paper presents the concept and development of a new fiber laser control unit developed to be used for CW, QCW or pulsed regime. Control unit could be used in multiple laser source and satisfy complex requirements. The control unit of the fiber laser source is able to be used in a different type of fiber laser like: Yb doped fiber, Erbium fiber, thulium fiber. Control unit is designed to be used direct or with minimum modifications in different laser processing applications like: marking, engraving, cutting, drilling, welding, etc. Main parameters of control unit are: 3 working regime, frequency - 1 KHz (QCW), frequency in pulsed regime : 15KHZ - 500 KHz, control seed laser, control pre amplifier and amplifier. Control unit allows commands for machine control: start/stop, interlock, system ready/ fault.

Keywords: Fiber laser, Control unit, Fiber laser control, Laser processing

Introduction

LASER is an acronym for ***L***ight ***A***mplification by ***S***timulated ***E***mission of ***R***adiation. *Laser marking* is an application very used today in different industries like: machine production, automotive, aerospace, marketing etc. Main applications are related to mark a bar code, data matrix, serial number or on different types of components, parts, etc, Laser marking is used in marketing, commercial applications like: jewellery marking, logo, image, watch etc. Marked products are made from metals or non-metals like: wood, plastic. Laser marking has main advantage that is not easy to be removed from marked product but has also a big disadvantage from same reason. In case of a marking error, it needs to replace the part with a wrong marker and this is a problem especially for strictly controlled production. Laser marking is used as method to avoid counterfeit and for brand protection.

The main advantages of various types of laser marking are (Lazov, Narica, Deneva, 2015):

- durable process;
- non-contact technology;

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

- precise beam focusing;
- high speed machining;
- high contrast and quality of the treatment;
- high productivity and low operation cost;
- good accessibility, even if the surface is irregularly shaped;
- easy automation and integration in the manufacturing process;
- prompt localization of laser energy to the work piece;
- high accuracy;
- environmental technology.

Laser engraving is a particular case of laser marking, based on removal of material.

Laser Marking Methods

There are eight laser marking methods detailed below (Lasers, 2021; Marking Lasers, 2021; Optoelectronica 2001; Security Document Solutions, 2021; Laser Etching, Engraving & Annealing, 2021; Laser Marking, 2021; Cook, Cooper, & Tentzeris, 2013; Laser cutting makes antennas greener, 2013):

i) *Laser Engraving / Evaporation* **-** Engraving (Figure 1a, b) creates high heat during marking, which causes vaporization of the material. Material is removed during the process. Laser processing effect is concentrated just to surface avoid (Figure 1a, b).

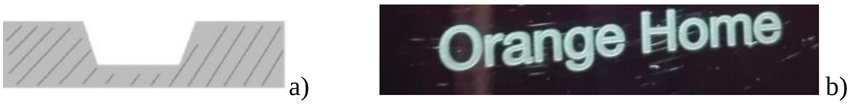


Figure 1. Laser engraving - a) draft/outline principle, b) example

ii) *Laser etching* **-** Etching (Figure 2) occurs when laser beam heat and melt material of the surface. Melted material expands, causing a raised mark. Is named sometimes melting or foaming.

Figure 2. Laser etching - a) draft/outline principle, b) example

iii) *Laser Bonding* - Pigment (Figure 3) or other coating is applied to the surface of material. The heat generated by a laser beam bond coating to the surface.

Figure 3. Laser bonding - a) draft/outline principle, b) example

iv) *Laser coat* – This marking method is used when it is not possible to engrave directly the surface, because for example the surface is reflective. In that case surface of the material is coated with a paint or similar (Figure 4). When laser beam is directed to surface, laser beam remove coating and remains just surface. We have a contrast between surface non-coated and coating.

Figure 4. Laser coating - a) draft/outline principle, b) example

v) *Laser Coloration / Annealing* -
Coloration (Figure 5) is achieved by using low-power laser beam slowly across the material. This method uses pulsed laser regime and modify the pulse energy and repetition rate. Due to different surface heating, locally surface change the colour.

Figure 5. Laser coloration – example

It is also possible to coat the surface with a pigment (invisible), and under laser interaction the pigment become visible.

Annealing (Figure 6) is a particular case used especially in stainless steel medical tools marking. Tools suffer just a surface colour change because the surface is slow heated. There is no under surface engraving so for such case, there is no possible for bacteria or yields to remains.


a)

b)

Figure 6. Annealing – - a) draft/outline principle, b) examples

vi*) Laser ablation* - Ablation (figure 7) is the process of coated surface engraving. This method creates excellent contrast without affecting the underlying material.

Figure 7. Laser ablation - draft/outline principle

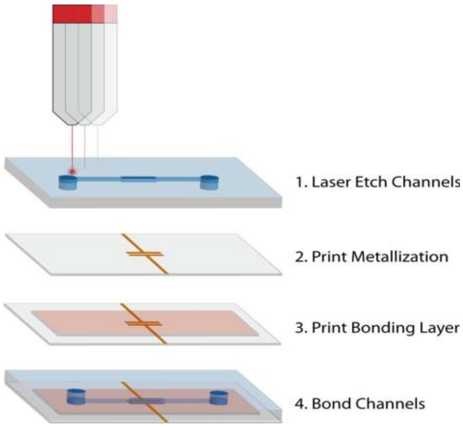
vii) *Deep engraving* - is the process when laser removes the material under surface level of tens or hundreds of microns. It is used for example in jewellery engraving, or in industrial engraving (figure 8a). In some applications, material removed is fill in with another material to get a contrast like in figure 8b.

a)


b)

Figure 8. Deep engraving – examples

viii) *Laser application in RFID*
In figure 9a is presented an application of fiber laser etch used in making RFID. In figure 9b is another use of fiber laser engrave or cut used to obtain an RFID antenna. Antenna is printed on a substrate using metal ink and laser is used to engrave the exact profile of antenna or just to cut the antenna.



a)

b)

Figure 9. Laser application in RFID techniques – a) RFID laser etch, b) RFID laser engrave/cut

Laser Marking Machines

From point of view of marking machine there are 2 types of marking principles. Each type is used in appropriate application (Lazov, Narica & Deneva, 2015).

i) *Raster Marking* - is similar with principle of dot matrix printer. In this case there is a laser beam that interact with object instead of pins push by printing head to a ribbon and paper. The laser mark spot by spot on a line, after that the laser is moved to next line and mark a line of spots. Raster marking is used in applications were is necessary high speed, especially when are marked texts. Rarely this method is used to mark drawing images (photos/logos), i.e., where there is no need to have high quality and high volume of information (figure 10).

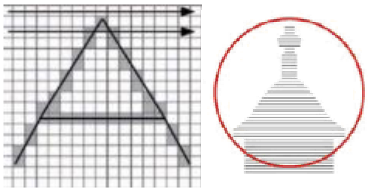


Figure 10. Raster marking

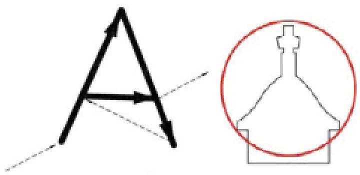


Figure 11. Vector marking

ii) *Vector marking* – This marking principle is used especially when it is need to have quality in marking numerical codes, bar codes, logos, etc (figure 11). Laser marking is like line drawings.

Both marking methods: vector and raster are implemented in fiber laser marking machines.
A fiber laser marking machine can be built in two construction types:
- with galvanometer head,
- with gantry or plotter type.

In this paper we consider galvanometer type fiber laser marking machine. Such type of machine is composed by: fiber laser source, galvanometer head, optical system, electronics. To develop a high quality fiber laser marking machine it is need to have: high quality fiber laser source, high quality optics. Laser source can work in CW in QCW or in pulsed regime. Below we will describe development of a adaptable fiber laser control unit used in laser source for fiber laser marking machine.

Method

Fiber Laser Control Unit Development

Below we will present the development of adaptable Control Unit (CU) for MOPA fiber laser (Optoelectronica 2001 S.A.). Control Unit is adaptable because with minimum of modification can be used for different types of fiber laser: CW, QCW of pulsed fiber lasers. In figure 12 it is presented MOPA fiber laser control unit (Optoelectronica2001, 2015) the fiber laser block schema Fiber laser is composed by seed laser, pre amplifier, amplifier, cooling system, control unit and output system.

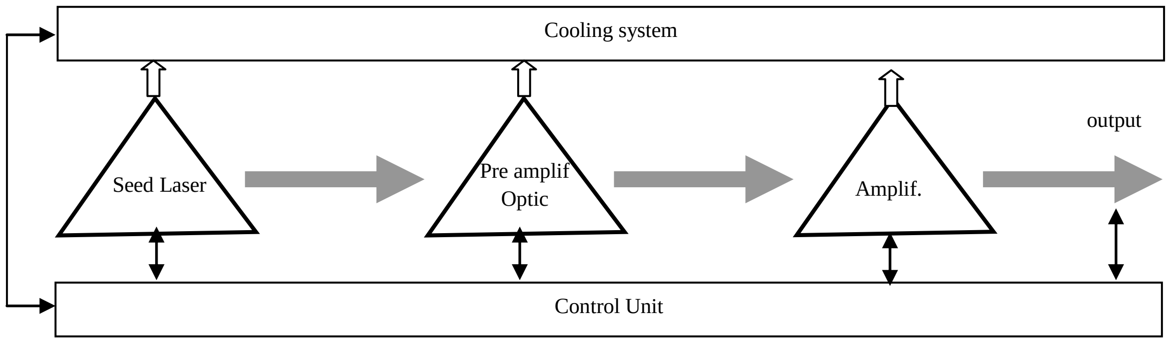


Figure 12. Fiber laser block schema

The CU is designed for MOPA fiber laser, and schema of such laser is shown in figure 13.

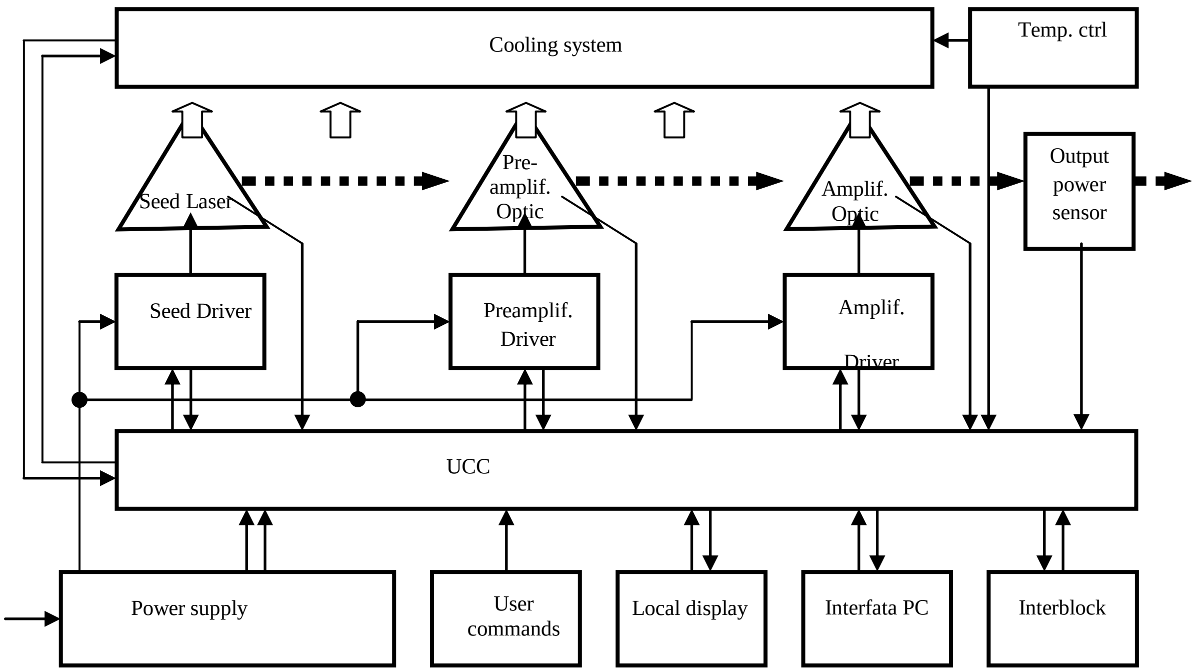


Figure 13. MOPA fiber laser

The MOPA fiber laser is composed by following assemblies:
Seed laser
Pre amplifier
Amplifier
Temperature measurement loop
Output power sensor loop
Cooling system
CU
Display
PC interface
Interblock
Power supply
MOPA fiber laser has 2 users: administrator (full access) user (limited access).
Commands that should be able to execute the CU are:

For LASER SEED:

- Command " Pulse Laser " - TTL output
- Read performing laser pulse - input TTL
- Read temperature fault driver - TTL input
- Read seed laser damage - TTL input

For Pre-Amplifier:

- " Pulse Laser " - TTL output
- ' current simmer ' - 0 -10V analogue output
- ' diode current " - 0 -10V analogue output
- Read diode current real - 0 -10V analogue input
- Read temperature fault driver - TTL input

Optical Amplifier:

- Pulse Laser - TTL output
- current simmer - 0 -10V analogue output
- diode current - 0 -10V analogue output
- Read diode current real - 0 -10V analogue input
- Read temperature fault driver - TTL input
- Laser Marker
- PWM output

Cooling System Command:

- Command cooling - serial RS232 / TT
- Command emergency cooling system - TTL input an optical floor to control the operation:
- Command diode temperature Pre-amplificator Optic - analogue input
- Command temperature diode optical amplifier - analogue input
- Command temperature fiber - analogue input
- Read laser power output - analogue input one for control commands and external interlock:
- Read switch " Interlock " - TTL input
- Read general emergency switch 'red button' - TTL input
- Read laser control switch type pedal - TTL input one for control commands from an external device:
- Read command " START Laser " - TTL input
- Read command " Fault" - TTL input
- Read command " External " - TTL input
- Command laser output power - 0 -10V analogue input
- Analog "external" - 0 -10V analogue input
- Order Laser Marker - TTL input
- Signalling ' System ready " - TTL output
- Signalling " Fault " - TTL output
- System for interfacing with a PC computing
- Serial Bus USB
- human operator for the local interface
- LCD with Touch Screen
- Generic interface: 4 digital lines

Administrator

CU developed has following working regimes (figure 14):

-*Continuous (CW)* – pumping diodes and seed diode are fed and laser radiation laser output power is controlled from the control current optical amplifier.
-*(QCW)* – pumping diodes and seed diode are fed, modulated (PWM) and laser radiation output power is controlled by the optical amplifier current command and the duty cycle of the PWM modulation - operating frequency 1Hz - 1kHz, 10% modulation - 90 %

-*Pulsed (P)* - seed diode is controlled by high frequency (15kHz - 500kHz) pulse duration is controlled in the ns regime. Current of the diodes in the pre amplifier and amplifier length is modulated (PWM) duty cycle also QCW mode is given by the number of laser pulses required functionality.
Thus, in this regime can control - Output frequency laser pulses, amplitude, duration and pulse train length.

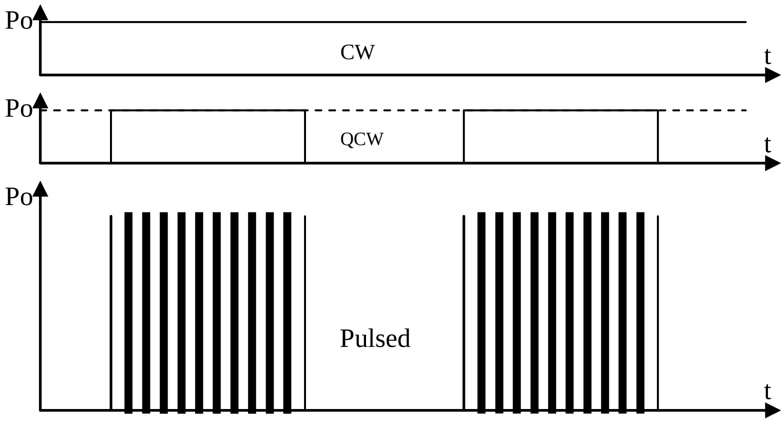


Figure 14. Working regime

Table 1. A CU developed as is described has following performances:

Parameter	Value
Working regime	CW, QCW, PULSE
Current command Pre amplifier driver	0 -10V- customized
Power supply command, Amplifier Driver	0 -10V- customized
Frequency command in QCW regime	1Hz .. 1KHz- customized
Frequency command in PULSE regime	15KHz…500KHz
Duty cycle QCW regime	1% … 100%
Pulse width	20ns ….500ns
Width pulse factor (multiple of)	10ns
External interface	UART, I2C
Outer command for machine tool	Output power
Outer command from machine tool	Start LASER
Outer command from machine tools	Start Laser Mark
Outer command from machine tool	System Ready, FAULT
Local commands	Interlock, Red push button
Local display	LCD, Color 65K, 480x272
Chiller control	UART
MTBF	100.000 hours
Cooling	Air/water
Power supply	5Vcc ± 5%
Maxim weight	300g
Size	180 x 120 x 25 mm
Temperature range	10 – 40^{o}C
Storage temperature.	0 + 50 ^{o}C
Humidity	5 - 85 %

Administrator MODE

Using an RS232 connection and connecting CU to a computer an administrator has access to the device using available commands (delete/insert CW/QCW/PULSE commands) as well as a quick sensors overview. Upon connection the admin is greeted with a message to provide authentication:

- log in: "***admin***"
- password: ***"ADMIN".***

User Mode

The user has access to 3 screens: command type selection, command selection (from the previously chosen type) and a screen to use the selected command.

Command Type Selection Screen

First the command class is chosen (by pressing on the "CW"/"QCW"/"PULS" icons). If there are no commands of that type in memory nothing will happen. To add commands, use a RS232 connection, log in with admin credentials and add commands

Command Selection Screen

All commands of that type will be displayed (left side of the screen), with a short description of the selected command in the right side of the display, to cycle trough the commands the buttons in the bottom left of the screen can be used.

In dynamic regime pulses for command optical pre amplifier and optical amplifier are in PWM regime with adjustable frequency in range 1 Hz - 1000 Hz and duty cycle between 10% and 90%. Pulses for seed laser has adjustable width in range 20 ns - 100 ns and frequency adjustable in range 15 KHz - 500 KHz. As conclusion we need a micro system able to control:

- 9 TTL output
- 14 TTL input from which 8 fault signals (critical)
- 3 UART serial line
- 1 serial line I2C
- 4 analog output from which one is critical (optical amplifier command)
- 8 analog inputs from which one is critical (Optical amplifier command)
- digital signal generator in rage 15KHz - 500KHz with controlled pulse in domain 15KHz- 500Khz with controlled pulse in the range 20 - 100ns.

Analog resolution are chosen for 0.1% error accordingly 1000 levels and accordingly 10 bits - 1024 levels.
Pulse generator clock should be Fck = 1/Tmin and correlated
Fck = 1/20ns.
Fck = 50Mhz
Resolution of pulse generator should be:
Nmax > Fck/ Fmin,
N> 50MHz / 15kHz, so N > 3333
We choose N = 4096 (12biti)
Rezolution of PWM generator is given by minimum and maximum frequency and control of duty cycle should be minimum in range 1-1000 -keeping error in limit 0.1%.
So, for maximum frequency of 1KHz timer clock should be
Fck = 1000 x Fmax,
Fck = 1000 x 1 kHz, Fck= 1MHz
Minimum frequency is Fmin = 1 Hz
Minimum resolution of timer PWM is: N = Fck / Fmin, N = 1.000.000. Because of pre-existence scale in micro systems: 1,8,64,256 and 1024, minimum resolutions attributes:
N1 = 125.000 according 17 bites and prescaler 8

N2 = 15.625 according 14 bites and prescaler 64
We chose needed resolution for PWM timer 16bits.
So, it is need to use a micro controller that fulfil followings criteria:

- Convertor Digital Analog (DAC) 10 bites;
- Convertor Analog Digital (ADC) 10 bites integrated;
- Interruption (INT0);
- Internal timer intern minim 50MHz (20ns pulse) with minim 12 bits;
- Timer with PWM with minim 16 bites;

We choose microprocessor Atmel AT90PWM3B.

Results and Discussion

The CU build according design consideration presented in paper is shown in figure 15.

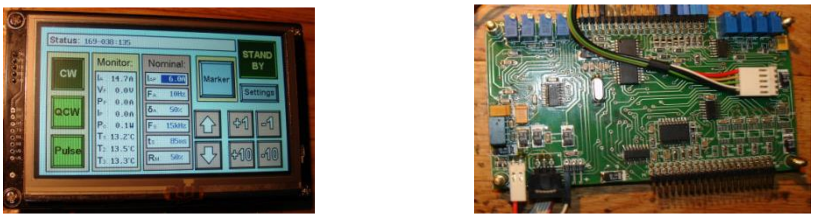


Figure 15. Fiber laser control unit – a) front face, b) back face

We assembly the fiber laser CU in a MOPA fiber laser. MOPA fiber laser is assembled in a laser engraving machine type galvanometer style.

In figure 16 there is presented the seed laser. Seed laser is composed by a seed diode emitting on 1064 nm +/- 5 nm. Diode is mounted on a laser driver. Driver allows CU control, connection with power supply from fiber laser.

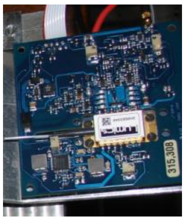


Figure 16. Seed laser

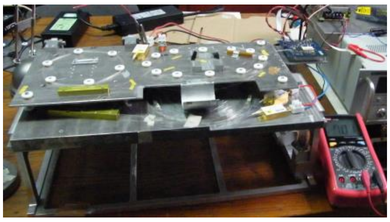


Figure 17. Fiber laser assembled

Figure 18. Laser output

In figure 17 is shown the fiber laser assembled. Right side is seed driver with diode mounted. In center is pre amplifier and amplifier.The CU is assembled on the front face of laser structure. Is not shown in the figure 17? In figure 18 is presented the laser emission of laser at output of MOPA fiber laser. Visually is demonstrated the quality of laser and practic were tested using dedicated device and result were M2< 1.5.

We make some tests in order to check the usage of CU for a MOPA fiber laser:

- output laser quality (see figure 18)
- laser power stability
- laser working regime
- output power
- engraving test

First test were demonstrate in figure 18. Laser power stability were check in following manner. The lasers were started and work 5 min without laser emission. Laser emission were started, CW regime were defined and power were increased until 3W were measured with laser power meter. Lasers were in function for 5 minute.

After that we start the laser stability test and we measure laser power with powermeter at each 5 minutes for 1 hour. The laser is stable and the graph is shown in figure 19.

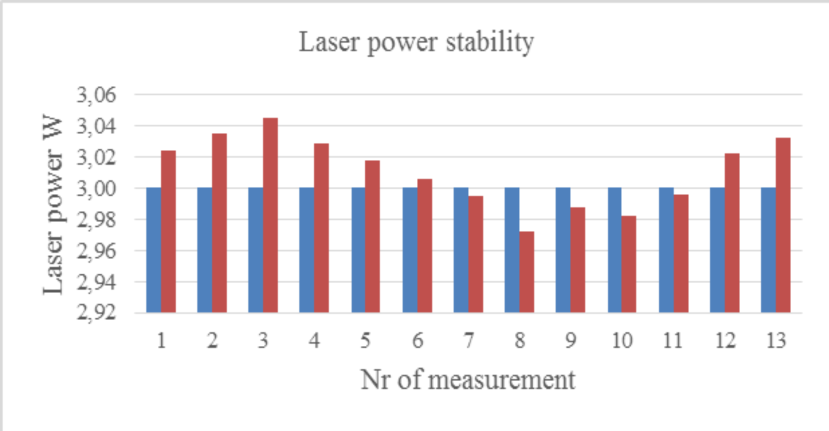


Figure 19. Laser stability measurement (legend blue – reference level, red – experimental values)

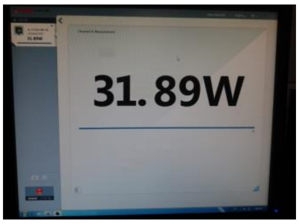
For working regime, we program the laser to work in CW regime and we are waiting 1 hour at 3 W and another 1 hour at 5 W. Laser works.
For laser QCW we program the laser to work and we are waiting 1 hour (figure 20 a,b,c). Laser works well.

a)


b)


c)

Figure 20. Laser work programming - a) laser working regime selection, b) example of QCW program, c) laser working regime example



a)


b)

Figure 21. Laser power measurement – a) juno +F150A, b) laserstar +F150A

To test output power, we put laser to work in CW regime and we increase the power slowly up to maximum. We notice that maximum laser power is 100W. In figure 21a and figure 21b are examples of laser power measurements. Measurements were executed with Ophir instruments: Laser star with head F150A-BB-26 and Ophir Juno with same head. MOPA fiber laser equiped with CU works well.

Conclusion

We design execute and test a adaptable control unit for fiber laser MOPA style.
The CU is adaptable because can be used for different types of lasers with minimum modification.
The CU can be programmed to work in 1, 2 or all three-working regime with minimum modifications. Such type of CU allows develop a family of fiber lasers working in different regimes.
We demonstrate possibility of such CU to work.

Acknowledgements or Notes

The research results were obtained within the research project "Combined technologies for high security intelligent multilayer hologram development - TECOMHOLISIG "- 2020 - 2022under call **PN-III-P2-2.1-PTE-2019-0578.** The Laser unit was designed and realized in the" Production of a new type of fiber optic laser within the company S.C. FIBER LASER OPTICS S.R.L" – INOFLO research project (2013 – 2015)

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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To cite this article:

Comanescu, B., Schiopu, P., Vladescu, M. & Iliescu, M. (2021). Adaptable fiber laser control unit. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 16*, 87-97.