

Protection against electric shock in electrical engineering didactic laboratories

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Abstract: *In order to rise safety level of the users in real laboratory environment related to the courses of electrical engineering the description and application examples of cover for laboratory screw terminals for use in research laboratories and experimental electrical systems and equipment is depicted in this paper. The main advantage of the described covers is the protection of laboratory personnel and students against direct contact to metal parts of terminal, which are under high voltage potentials. The paper points out the necessity for protection measures and contains examples of use of different covers for electrical machines, power converters, electric meters and other laboratory equipment.*

Keywords: *electric shock protection; cover; insulator; electric screw terminals; laboratory accessories*

1. INTRODUCTION

During still actual global health crisis caused by Covid-19 virus a huge number of teaching activities is dislocated to online platforms using different online didactic resources [1]. Moving student's practical laboratory exercises to online world was serious challenge with very attractive results and outcomes [2,3]. Implementation of the remote laboratory experiments have faced its creators with numerous challenges in solving real-time synchronised video streaming, experiment booking time slots, protection against unallowed actions, steps, etc. Contrary to this completely user friendly and save environment for students and other online users, traditional approach in real laboratory demands precautions related to electric shock protections and protections of laboratory equipment. Coming back from online resources to the real laboratory premises demands increased caution since online work tend to rise inattentive and careless approach during performing laboratory exercise [4]. Having that in mind this paper presents various electric shock protection applications aiming to prevent potential hazard caused by accidentally contact with high voltage potential points in electrical engineering laboratories.

The most exposed high voltage points in laboratories are screw terminals used to connect the circuits between the wirings of electrical machines, the terminals of meters, the terminals of supply transistor converters and the terminals of supply electric power grid according to delivered scheme by teacher or the scheme drawn by students or by researcher. The screw terminals are

widely used in the research and the didactical laboratories such as: in the laboratory of numerical control [5], in the laboratory of the mechatronics [6], laboratory of the electrical engineering and informatics [7], laboratory of the industrial engineering [8], laboratory of superconductive materials [9], laboratory of agriculture [10], laboratories of electrical and computer engineering [11], laboratories for automatic electrical drives [12], laboratory of electrical machines [13], laboratories of the power electronics [14], laboratory of electrical engineering and electrotechnology [15], and in laboratory of mechanics [16]. The screw terminals are used in research laboratories in experimental set up for series connections of supercapacitors [5], for the connections to the electrical machines [9], [11], [12], [13], [17], in laboratory adjustable autotransformers [18], in the isolated measurement system connected to the computer and in the main distribution research table [6], for safety connections [10]. The screw terminals are utilized in different kinds of devices such as: in the meters [9], in the laboratory programmable DC power suppliers [8], [11], [14], in the prototyping devices [7], [12]. The screw connections are also used in a plasma reactor [15], for electromagnet in laboratory set-up for testing [19] and for three phase diode rectifiers in marine energy conversion system [20].

The screw terminals are not only used in the laboratory equipment, but they also can be used in the industrial devices like the welders, the battery chargers, and in domestic devices like sets of loudspeakers to connect with amplifier, etc.

The wide use of the screw terminals is the result of its basic advantage, that is difficult to disconnect accidentally the electrical circuit. The electrical and mechanical connection of screw terminals is assured even using the strong mechanical forces when accidentally pulling the cable. This basic advantage is very important especially in the laboratory of electrical machines, because it allows to prevent from many unwanted phenomena. The excitation current of separately excited DC motor or separately excited synchronous motor cannot be interrupted rapidly. The rapid interruption of the machine excitation current causes the overload current in the main armature circuit. The interruption of excitation current of DC motor can cause high and dangerous motor speed even hazardous burst of the rotor due to high centrifugal forces.

The current rapid interruption can also cause the dangerous electrical arc burning insulators and melting metals especially in circuits especially with devices like electrical machines. The electric arch in devices can cause the electrical surge between disconnected terminals originated from machine winding inductance. The electrical surge can damage semiconductor devices supplying electrical machines, e.g. diodes of rectifiers or even can cause electrical shock of surprised laboratory personnel. The application of screw terminals ensuring high quality connection prevents laboratory devices and personnel from current rapid interruption and all unexpected phenomena mentioned above.

The screw terminals for use in laboratory are shown in Fig. 1. In order to connect a circuit, the fork terminal 1 ending cable 2 with terminal handle 3 is put under the handle 5 of the screw terminal 4 and then is tightened by screwing the handle 5. The handle 5 is made of isolation material, which do not conduct the electrical current. The application of isolation material allows the personnel to touch it safely and to screw terminal and to unscrew it. The disconnection of the fork terminal 1 from screw terminal 4 is obtained by unscrewing the handle 5 and pulling back the fork terminal 1.

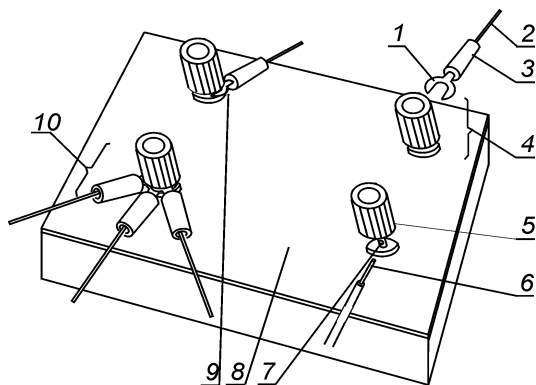


Figure 1. The screw terminals on mounting plate

The screw terminal 4 can be also used for connection with bare end 6 of wire with removed isolation. The screw terminal 4 has a whole 7 in its screw in order to put inside the bare end 6 of wire.

All the screw terminals 4 are mounted on mounting plate 8, which is made of isolating material which do not conduct electric current.

The main disadvantage of using screw laboratory terminal is that, the metal basis 9 of screw terminal and the metal part of fork terminal 1 are exposed, and there is a possibility to touch the metal parts 1 and 9 clamped in the terminal 4, as shown in Fig. 1. Amount of available active metal components under high voltage rises, when a single laboratory terminal tightens several fork terminals, as indicated by reference numeral 10 in the Fig. 1. Continuing, in accordance with electrical standards it should not occur access to active metal components conducting an electrical current after the connection of an electrical circuit.

2. COVER AGAINST DIRECT CONTACT WITH LABORATORY TERMINALS

The essence of the technical solution is the apply the cover made of not conductive material of appropriate shape enclosing screw terminal 4 (Fig. 1) with clamped fork 1 or clamped the metal end 6 of the cable. The proposed cover of laboratory screw terminals is shown in Fig. 2.

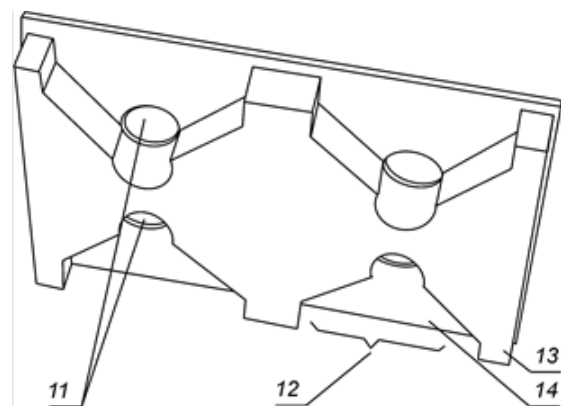


Figure 2. The bottom view of cover for four laboratory screw terminals

All potentially dangerous parts of connection of an electric circuit: a screw terminal 4, a bare end 6 of the wire without insulation, a metal active part 9 of the terminal laboratory screw, are covered by cover shown in Fig.2. As the result, the main advantage is that, the cover protects student and laboratory personnel against direct contact with active bare metal parts of laboratory terminals after the connection of the circuit.

Cover has a hole 11 in the middle, for the handle 5, and the empty spaces 12 in it, for restoring in: the terminal 4 and one, two or three fork terminals 1, as it is depicted in Fig. 2. The empty space 12

may be obtained by cutting the space in the thick plate element 14 made of insulating material do not conducting electricity. The empty space 12 for the fork terminal 1 is covered by an insulating material plate 13 with holes 11 on handle 5 of terminal 4. Cover allows, without removing it, clinching and disconnection the fork terminal 1 or metal cable end 6 from screw terminal 4. In other words, the handle 5 can be turned on and off when the cover is placed on the terminal 4.

Another advantage of the protection solution is a simple construction of the cover. The cover is made of two pieces of plexiglass plates, one 13 is thick and the other 14 is thinner. Thicker plate element 13, which is shown in Fig. 3a, has a cut 12 for fork terminals 1. Thinner plate element 14 has holes 11, which are shown in Fig. 3b. The holes 11 are there in order to allow for a handle 5 to protrude over the cover, and to allow for a user to grip the handle 5 and to screw it and to unscrew it, as shown in Fig. 3c. The result of installation of a cover 15 on a set of screw terminals with an insulated handle 5 on mounting plate 8, is shown in Fig. 3c. The cover of the laboratory screw terminal can be made of any insulating material: transparent or opaque.

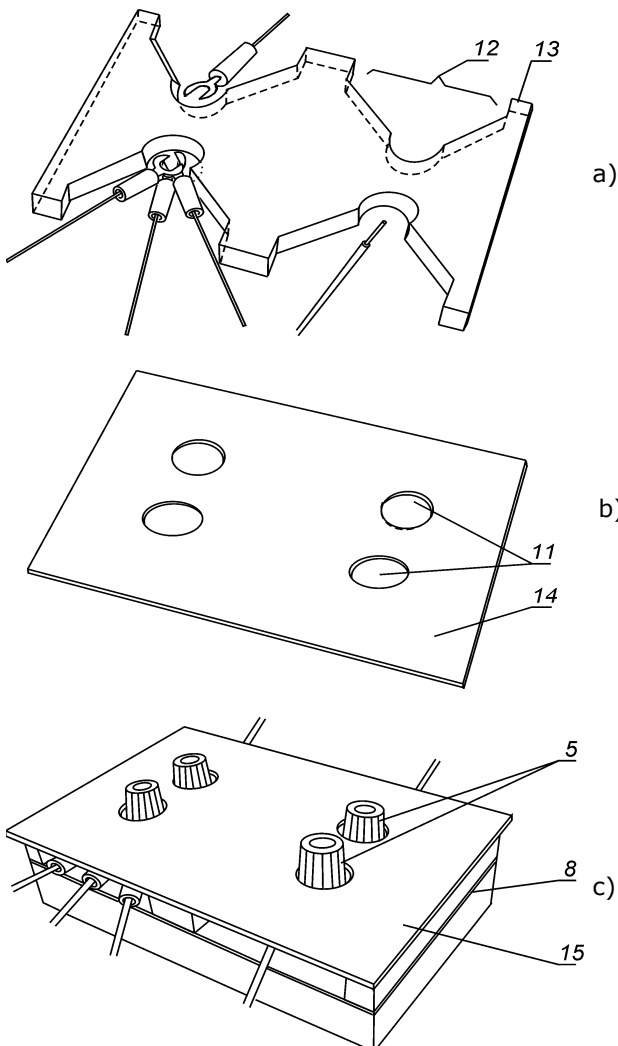


Figure 3. The set of the screw terminals: thicker plate (a), thinner plate (b), cover (c)

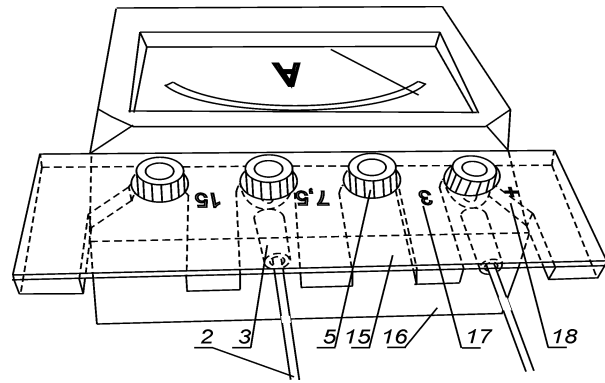


Figure 4. The set of the screw terminals and the cover

The example of the cover, which is made of a transparent material such as acrylic glass used for laboratory meter is shown in Fig. 4. The material transparency is critical to the cover functionality, especially when using it to cover the set of screw terminals of the laboratory electric meter 16. The use of a transparent material for the cover has such the advantage that the markings of the measurement ranges 17 and the markings of the polarity 18 are visible under the cover 15. In the case of application of transparent cover, the user will see not only the textual descriptions 17 or the graphic signs 18, but also the schemes of electrical circuit under the cover.

One laboratory screw terminal can tighten several fork terminals 10 in Fig. 1. Therefore, the cover of laboratory screw terminal may be designed to cover one or several fork terminals 1. Fig. 5 contains the perspective view of the bottom of the terminal cover designed for the electric meter (Fig. 4). In Fig. 5 cover has two empty spaces: whole 11 and empty spaces 12. The empty spaces 12 can be used for one and for two fork terminals that can be connected to the screw terminal.

The terminal cover can also be used not only for the laboratory equipment, but also for industrial equipment, or household appliances. The example of embodiment of the covers 15 of screw terminal 4 for battery rectifier 19, autotransformer, welding inverter, column loudspeaker is shown in Fig. 6. Screw terminals and the cover are also used in sets of electrical machines. The embodiment of covers 15 of terminals 1 and 4 for three phases induction motor 20 and for DC tacho-generator are shown in Fig. 7.

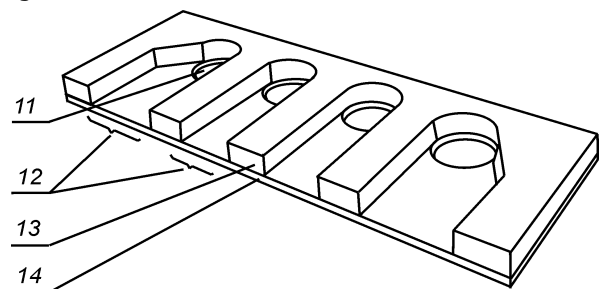


Figure 5. The view of the bottom of the cover for the laboratory screw terminals

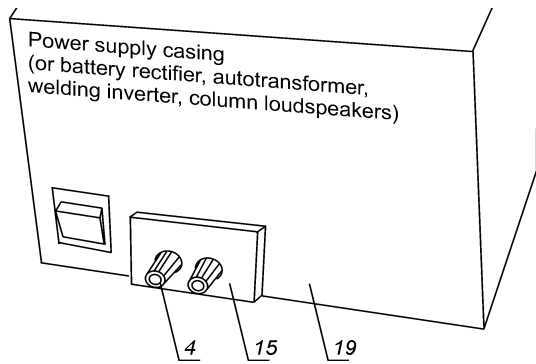


Figure 6. The cover of screw terminals of industrial device or household appliance

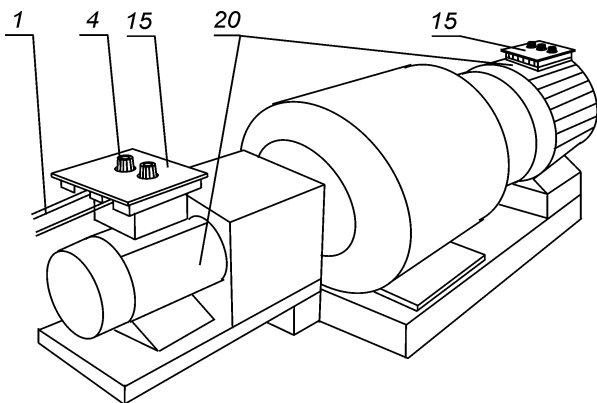


Figure 7. The cover of screw terminals for electrical machines

3. THE EXAMPLES OF APPLICATION

The examples of covers for different applications are described in this chapter. In Fig. 8 covers for laboratory meters are shown, which are manufactured by company Mera Gostynin: for wattmeter 21, voltmeter 22 and amperemeter 23. All covers are made of transparent material plexiglass. Because of cover transparency, the descriptions of wattmeter 16 ranges 17 and wattmeter voltage coil polarity 18 are visible for user, like it is shown in Fig. 9. Cover 15 allows to connect one fork terminal 3 to one screw terminal 4 of wattmeter 16, as it is shown in Fig. 9. However, cover 15 can have wider zone 12 for connection many fork terminals to one screw terminal, like is shown in Fig. 12 and in Fig. 14. Cover is narrow enough to make possible for user to take with ease isolated part 3 of fork terminal with fingers, like is shown in **Error! Reference source not found.**

Covers are composed of three layers. In previous figures **Error! Reference source not found.** – Fig. 7 the only two layers 13 and 14 are shown. The third layer 25 is glued to the bottom of cover 15, as it is shown in Fig. 10. The templates of all layers 13, 14 and 25 of cover for amperemeter are shown in Fig. 11. The cover 15 assembled from those three layers 13, 14 and 25 are shown in Fig. 12. The third layer 25 was applied for two reasons.

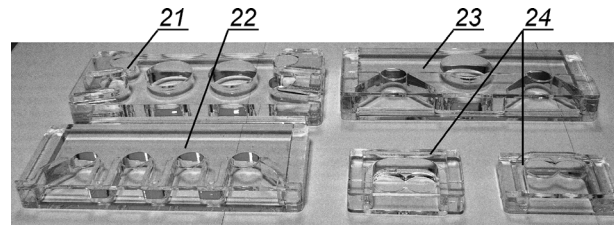


Figure 8. The examples of covers for different laboratory electrical devices

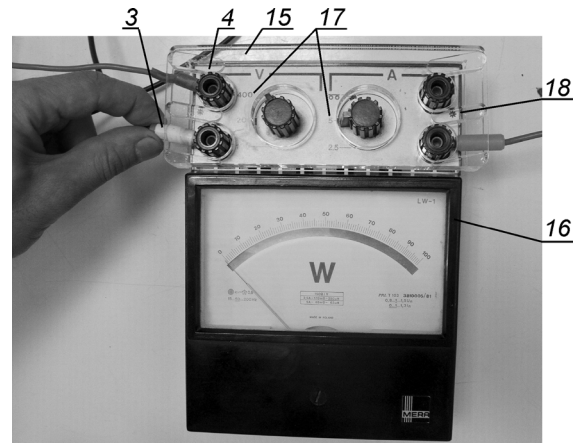


Figure 9. The application of cover for power meter terminals

Firstly, to prevent cover from dropping down when meter is turned upside down. In **Error! Reference source not found.** 10, when voltmeter 16 is reversed the fork terminal with cable do not allow the cover 15 to drop down.

Secondly, the third layer is applied in order to prevent user putting finger into zone 12 and to prevent touching the metal parts of connection under high voltage, like is shown in Fig. 12 **Error! Reference source not found.** The finger can not pass through the zone 12, because height of zone 12 equal 10 mm is lower than average width of a grown human finger. The zone 12 does not prevent from contact with using special thin conductive elements that can be put inside this zone. However, it should be understood, that the cover protects user only from unconscious and accidental touch of metal parts of connection.

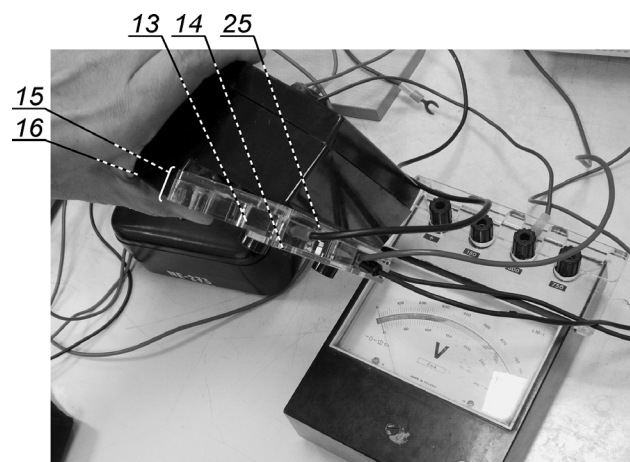


Figure 10. The view of terminal when meter is tuned upside down

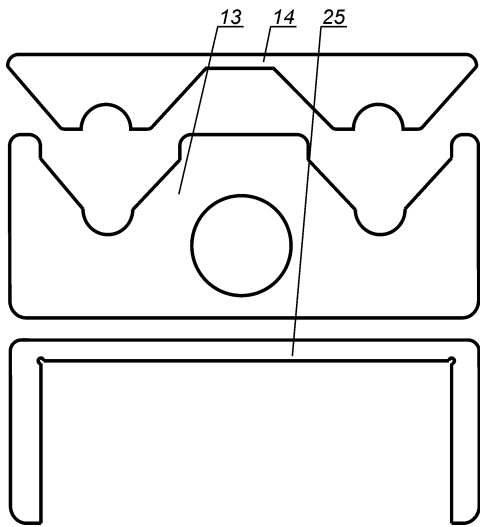


Figure 11. The templates of all layers of cover for amperemeter

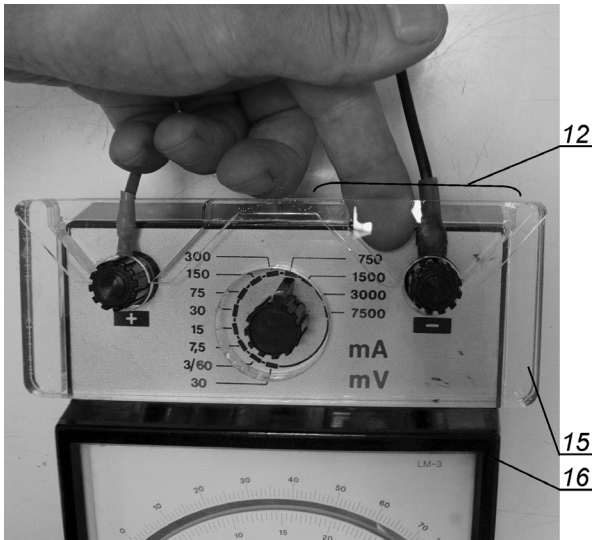


Figure 12. The view of cover for laboratory amperemeter when trying to put a finger into the zone 12

The covers 15 in application to laboratory autotransformer 26 are shown in Fig. 13. The fork terminal 3, screwed in screw terminal 4, blocks cover 15. As the result, taking back cover 15 is not possible, because of the existence of the third layer 25.

The application of the cover to the electrical machines are shown in Fig. 7 and in Fig. 14. In Fig. 7, the sets of screw terminals and the covers 15 are mounted directly on the electrical machines. In Fig. 14, the sets of electrical machine terminals are mounted on the laboratory table 28 away from the electrical machine. The main advantage of application terminals away from electrical machine is that, all the singular connections are done on the laboratory table and any cables does not hang from

table towards electrical machine. As the result, user has no possibility to accidentally tie himself with these cables. The case 7 with screw terminals 4 are connected to electrical machine with cable 27. As it was mentioned before, the transparency of cover makes the scheme 29 of DC machine wirings and the symbolic names of terminals visible.

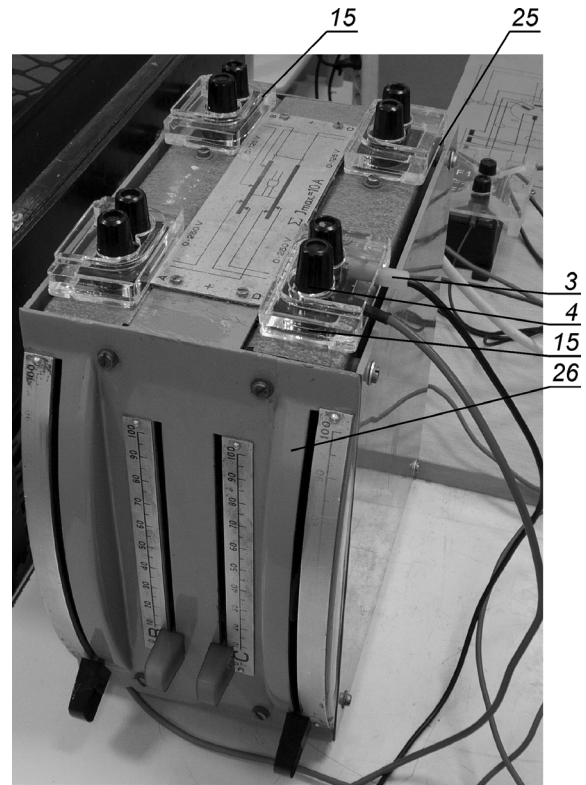


Figure 13. The application of the cover for the laboratory transformer terminals

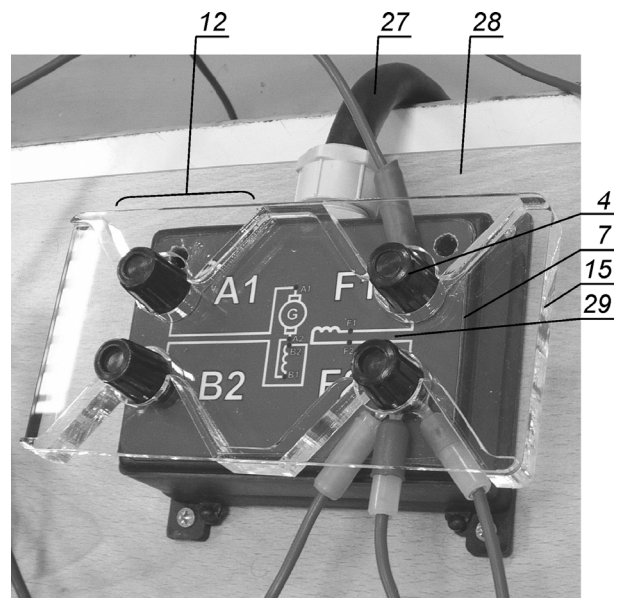


Figure 14. The cover application for the electric DC machine terminals

The cover can be used for terminals of other electrical equipment of research laboratories, for example, for the resistor, in Fig. 15. The cover 15

is mounted on the mounting plate 7 of the resistor 30 with screw 31 as it is shown in Fig. 16.

The cover can be used with screw terminals of different sizes. The application examples of cover for screw terminals with durability of 30 A and 100 A are shown in **Error! Reference source not found.** and **Error! Reference source not found.**, respectively.

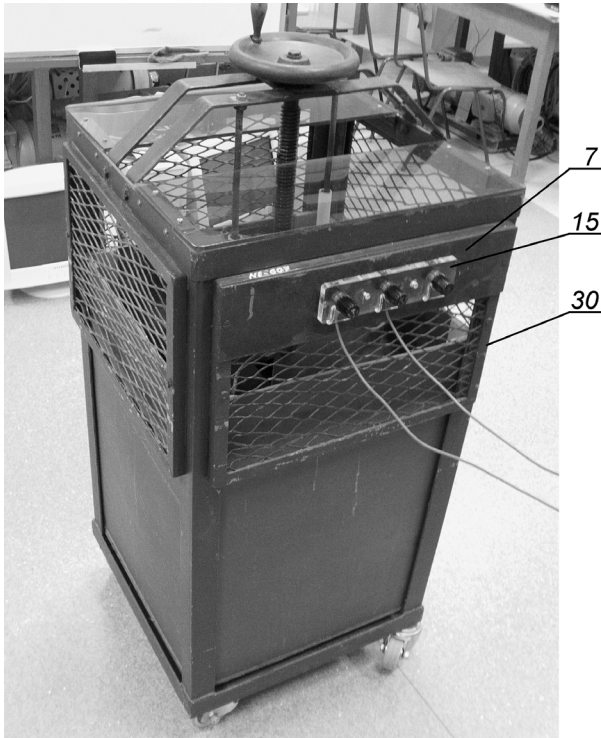


Figure 15. The application of cover for a adjustable resistor

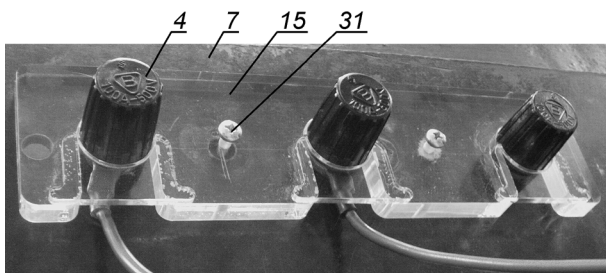


Figure 16. The application of cover for an adjustable resistor

4. CONCLUSION

The paper arose as an answer to emerging need to rise safety level of the electrical engineering laboratory environment in terms of prevent possible dangerous and hazard situations caused by laboratory staff and students. The paper presents various types of covers of the laboratory screw terminals can find its use in variety devices such as: sets of electrical machines: motors, generators, transformers, power electronics devices, electric meters (e.g. amperemeters, voltmeters, wattmeter), and in an industrial devices like welders, as well as in a house hold

devices like column loudspeakers or battery chargers, laboratory resistor etc. The cover can assure protection of laboratory personnel against the direct and accidental contact to metal parts under high voltage of the screw terminals leading to potential electric shock.

The cover has many additional functionalities such as transparency, can protect connections with one or with many fork contacts, can be applied with screw terminals with different sizes. After application additional third layer the fork terminal block cover from removal. It is important, because after connection the circuit it is not possible to remove the cover and the protection of laboratory personnel is ensured.

The simple cover design solves not only technical problems, but also sociological problems. The basic advantage of cover design is easy mounting without additional expensive devices for plastics forming by injection. The cover simply consists of three plate elements, which are cut from plexi-glass and fixed each other with glue. Because of easy mounting with glue, the cover can be mounted by differently enabled people. It is very important, because this feature allows to solve employment problem of those people a little bit and delivers opportunities for a tolerant society of people with different and full abilities.

ACKNOWLEDGEMENTS

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