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Marija Savković [1]
Miloš Petrović
Carlo Caiazzo
Marko Đapan
Arso Vukićević

DETERMINE MUSCLE STRAIN OF ASSEMBLY WORKERS BY APPLYING ADVANCED EMG MEASUREMENT

Abstract: *Contemporary organizations tend to improve the safety and health of workers through the relief of workers from performing strenuous and tiring activities. Musculoskeletal disorders (MSDs) that occur as a result of repeating the same movement over a long period of time, straining and bending the body or performing assembly activities in an ergonomically inadequate body position represent one of the major problems faced by organizations, which further leads to more and more absenteeism of workers from work, reduced productivity and increased costs.*
The main aim of the research paper is to show the results of monitoring of muscle activity during the performing of assembly activities in two scenarios - ergonomic and non-ergonomic. The non-ergonomic scenario involves performing assembly activities at a traditional workstation. On the other hand, in the ergonomic scenario, participants perform assembly activities on the proposed ergonomically designed workstation, in the golden zone and in this way bending, stress and stretching of the body are eliminated.

Keywords: *assembly workstation, EMG, egonomics interventions, musculoskeletal disorders, safety 4.0*

1. Introduction

One of the main goals of Industry 4.0, in addition to improving the effectiveness of production processes, is improving safety and health through the achievement of "zero injuries". This goal can be achieved through the elimination of injuries at work, minimization of occupational and work-related diseases, minimization of discomfort and stress. Safety 4.0 represents a shift towards a more data-driven, technology-enabled approach to workplace safety. Intelligent wearable devices and other modern technologies of Industry 4.0 enable real-time monitoring vital signs and tracking location of workers and identify potential safety risks (for example, detecting exposure to hazardous materials).

The increased automation of the production process and the application of advanced technologies of The fourth Industrial Revolution contributed the relief of workers from performing strenuous and tiring activities. However, many activities cannot be fully automated and workers are forced to perform assembly tasks that are manual and repetitive over a long period of time, which can lead to health problems that in some cases can cause permanent consequences to their health.

Corresponding author: Marija Savković
Email: marija.savkovic@kg.ac.rs

Assembly activities in the automotive, engineering and electrical industries are a frequent occurrence. Due to increased effort and muscle strain in workers who perform repetitive, complex, tiring and physically demanding assembly activities in non-ergonomic conditions for a long period of time, musculoskeletal disorders (e.g. carpal tunnel syndrome, joint tendonitis, etc.) and other occupational diseases occur. In a real industrial environment, workers most often perform these activities in a standing position at traditional workstations which additionally contributes to the deterioration of their health condition in the form of lower back pain.

In the member countries of the European Union (EU), musculoskeletal disorders are one of the most common diseases. According to statistics, about 60% of workers suffer from this type of professional illness (Assurance Maladie, 2020; Caroly, S., Major, M. E., Probst, I., & Molinié, A. F., 2013).

This group of occupational diseases is associated with a large number of lost working days during the year, and associated with this are significant financial losses suffered by organizations due to a drop in productivity and increased costs due to absenteeism. According to the study (Warner, M., Baker, S. P., Li, G., & Smith, G. S., 1998) due to the appearance of musculoskeletal diseases, there was a decrease in productivity by 65%.

As one of the main risk factors for the occurrence of disorders of the musculoskeletal system, bad posture and an inadequate ergonomically designed workplace are mentioned in the literature (Alexopoulos, E. C., Burdorf, A., & Kalokerinou, A., 2003; David, G., Woods, V., Li, G., & Buckle, P., 2008). While performing manual repetitive, precise assembly activities, the worker's head and neck are bent forward for long periods of time. This non-ergonomic position of the body causes pain in the neck and back (Chandrasakaran, A., Chee, H. L., Rampal, K. G., & Tan, G. L. E., 2003; Jonsson, B. G., Persson, J., & Kilbom, Å., 1988). Also discomfort is felt in other parts of the body - shoulders, arms, elbows, wrists, hand nerves and muscles or areas around these parts of the body.

In addition to the appearance of acute pain, there may also be the appearance of chronic pain in the mentioned parts of the body, and in some situations, permanent inability to work. According to the studies (Ohlsson, K., Attewell, R., & Skerfving, S., 1989) and (Ohlsson et al., 1995) conducted 39% of assembly workers in the automotive industry reported neck pain, 38% had shoulder pain, and 14% had arm pain. Luopajärvi, T., Kuorinka, I., Virolainen, M., & Holmberg, M. (1979) indicated that 37% of assembly workers complained of neck pain and 5.9% of arm pain.

Based on the above, it can be concluded that there is a need to improve traditional workstations in industrial environment. Good workstation design is crucial for industries that involve manual assembly activities by operators (Hägg, G. M., 2003). Monitoring the operator's muscle activity and identifying when fatigue occurs is of great importance, given that fatigue has a negative impact on the operator's health status (musculoskeletal disorders- back pain, carpal tunnel syndrome), productivity and operator's performance.

EMG as an electrophysiological method enables the registration of action potentials of muscle fibers of motor units that arise during muscle contraction. Using electromyography, muscle activities are monitored during the assembly of parts and components, and the load and strain on the muscles of the neck, arms and shoulders during these activities is determined.

The main aim of the research paper is to show the results of monitoring of muscle activity during the performing of assembly activities in two scenarios - ergonomic and non-ergonomic in order to establish the risks that lead to the occurrence of musculoskeletal disorders and other occupational diseases among workers who perform assembly activities at traditional workstations.

The non-ergonomic scenario involves performing assembly activities at a traditional workstation in conditions that simulate conditions from a real industrial environment. On the other hand, in the ergonomic scenario, respondents perform assembly activities on the proposed new modular ergonomically designed workstation. In that case, the respondents perform assembly activities in the golden zone and in this way bending, stress and stretching of the body are eliminated.

Ergonomic interventions at the new workstation involve adjusting the height of the work surface, providing adjustable seating, and ensuring that tools and equipment are within easy reach.

This paper presented the results of monitoring the muscle of participants who perform assembly activities for a long period of time in an no ergonomic body position, in order to determine the ergonomic risks to the workers.

The motive for writing the paper lies in the fact that neglecting ergonomics in workstation design can indeed result in work-related musculoskeletal disorders and another occupational and work-related diseases. Poor workstation design can force workers to assume awkward postures, perform repetitive motions, or use excessive force, all of which can increase the risk of injury. For example, if the workstation is too high or too low, workers may have to hunch over or reach up, putting strain on their back, neck, and shoulders.

2. The experimental study

2.1. Literature review

Assembly worksers occupational diseases and serious illnesses of workers, which can even lead to the disability of workers, which further leads to more and more absenteeism of workers from work, reduced productivity and increased costs. Neglecting ergonomic in workstation will result in workrelated musculoskeletal disorders. MSDs (including carpal tunnel syndrome, tendonitis, tennis elbow and back pain) are a particularly common problem among assembly workers, as their work often involves repetitive frequent motions, awkward postures, and forceful exertions (Choobineh, A., Lahmi, M., Shahnavaz, H., Khani Jazani, R., & Hosseini, M., 2004; Faucett, J., Garry, M., Nadler, D., & Ettare, D., 2002). These conditions can be painful and debilitating, making it difficult or impossible for workers to perform their duties and causing absentism.

According to the results of a Norwegian survey, the majority causes of MSD were: 65 % pain in the neck or shoulder region and 78 % arm pain (Mehlum, I. S., Veiersted, K. B., Wærsted, M., Wergeland, E., & Kjuus, H., 2009). Upper extremity disorders are a significant problem in assembly workplaces, both in terms of their commonness and the associated costs (Xu, Z., Ko, J., Cochran, D. J., & Jung, M. C., 2012). The costs associated with upper extremity disorders can be significant. Workers with these conditions may require time off from work for medical treatment or recovery, which can lead to reduced productivity and increased costs in organizations (“Ergonomics in the workplace”, 2019). In this context, many studies have proposed basic design rules or guidelines to ensure that assembly workers are able to work in safe and comfortable positions that minimize the risk of musculoskeletal disorders. These guidelines typically focus on ergonomic workstation design, which involves designing workspaces that are tailored to the physical and cognitive abilities of workers.

EMG signals are used to monitor workers' muscle condition. According to (Graham, R. B., Agnew, M. J., & Stevenson, J. M., 2009; Lundberg, U. et al., 1999) the level of muscle activity varies depending on the complexity of the task performed and the position in which the worker performs the activities. According to (Sommerich, C. M., Joines, S. M., Hermans, V., & Moon, S. D., 2000) surface EMG (sEMG) is a very reliable and valid tool for measuring muscle activity in a industrial environment. Using this method, it is possible to determine the maximum lifting load, lifting height, and the number of repetitions that the workers are able to handle before experiencing fatigue, all for the purpose of avoiding overexertion (Freitas et al., 2019).

In studies (Bongers, P. M., Ijmker, S., Van den Heuvel, S., & Blatter, B. M., Griffiths, K. L., Mackey, M. G., & Adamson, B. J., 2007) surface EMG was applied to investigate the effects of workstation redesign on muscle strain in workers performing assembly activities and it was concluded that muscle strain in the upper extremities and shoulders, including the trapezius muscles, was significantly reduced after the redesign.

In a study (Björklund, M., Crenshaw, A. G., Djupsjöbacka, M., & Johansson, H., 2000) the effect of a repetitive low intensity task to fatigue on shoulder position sense was investigated. Molinari, F., Knaflitz, M., Bonato, P., & Actis, M. V. (2006) assessed the changed spectrum of the EMG signals when fatigue occurred during dynamic muscle contraction. Also, EMG electrodes were used in a specially designed laboratory experiment simulating roofing jobs to examine the effects of common risk factors based on lower back muscle activity and working frequency (Wang, D., Hu, B., Dai, F., & Ning, X., 2015). The authors (Heydari, A., Nargol, A. V., Jones, A. P., Humphrey, A. R., & Greenough, C. G., 2010) conducted a large-scale study involving more than 100 workers (some with chronic pain symptoms and some not), testing the lumbar paraspinal muscles as a predictor of low back pain risk. Two years later, the research was conducted again on the same participants, and a subgroup of respondents with a higher risk of back pain was identified. In some scientific research papers, sEMG has been combined with observational assessments and self-assessments, in order to obtain a comprehensive picture of the extent to which muscle strain occurs in workers performing assembly activities.

2.2. Metodology

The traditional workstation where workers perform activities in a real industrial environment is fixed and not adapted to the individual anthropometric characteristics and capabilities of the operator. Also, workers in the industry most often perform assembly activities in a standing position for a long period of time, and this has a negative impact on their health conditions. In order to overcome the shortcomings of the traditional workstation, the authors proposed a new workstation that is aligned with ergonomic and lean principles and adapted to the individual characteristics and capabilities of the operator.

Studies (Corlett, E. N., & Eklund, J. A. E. 1983; Devereux, J. J., Vlachonikolis, I. G., & Buckle, P. W. , 2002) have shown that in an ergonomically designed workplace, the risk of musculoskeletal disorders is reduced, the safety and health of workers is improved, stress is reduced, and this further positively contributes to increasing the efficiency and productivity of operators. Authors (Choobineh, A., Lahmi, M., Shahnavaz, H., Khani Jazani, R., & Hosseini, M., 2004) concluded that the neglect of ergonomic principles at the workstation leads to work injuries and musculoskeletal disorders. (Brito, M. F., Ramos, A. L., Carneiro, P., & Gonçalves, M. A., 2017) showed that when designing a workstation, special attention should be paid to ergonomic aspects.

Performing activities in the golden zone reduces stretching, bending, reaching for materials and parts, and eliminates poor posture, which further contributes to increased efficiency and reduced activity time (Heilala, J., & Voho, P., 2001; Yusuff, R. M., & Abdullah, N. S., 2016) pointed out the importance of adapting the workplace to the physical characteristics, requirements, abilities and skills of workers.

2.3. Case study

The experimental study was conducted in the period March 2022-March 2023 in the laboratory for ergonomics and collaborative robotics at the Faculty of Engineering, University of Kragujevac.

Participants

15 respondents participated in both scenarios. The subjects were undergraduate, master's and doctoral students at the Faculty of Engineering, University of Kragujevac, male gender, right-handed, aged between 18 and 30, who do not suffer from musculoskeletal disorders and have no serious back or spine problems. All participants voluntarily participated in the experiment and signed the consent that they allow the data to be used for further analysis. Before performing the experiment, the subjects were familiarized with the procedure and their basic data (age, year of birth, height and weight) were collected.

Equipment

The experiment was performed using an EMG device. The EMG device used for advanced measurements was MuscleBAN BE, produced by the company PLUXSignals from Portugal (slika 1.). This portable and wearable device measures electromyography and motion data, enabling a wide array of biomedical research and physiotherapy applications („Plux Biosignals, MuscleBAN BE Data Sheet“, 2021). As the main features of this device, we can state that it is light and small, so it can be worn without causing the test subjects any discomfort or interfering with their work during the experiments.

Image 1. The MuscleBAN BE device (The image of the rash („Plux Biosignals, MuscleBAN BE Data Sheet“, 2021))

The Bluetooth capability at up to 10 meters means that there is no need for wires, which would similarly impede the workers during the experiment and increase its complexity. The signal noise is 3 mV, giving us the margin of error, though the very large number of data points (over 5 million measurements) obtained during each session should greatly reduce the effects of statistical noise on results. The main device’s characteristics, taken from its instruction manual, are presented in table 1. („Plux Biosignals, MuscleBAN BE Data Sheet“, 2021).

Table 1. The main device's characteristics

Communication	Bluetooth Low Energy
Range:	up to ~10m (in line of sight)
On-board Sensors	1 EMG; 1 Triaxial Accelerometer (±4g); 1 Triaxial
ACC resolution	14-bit
MAG resolution	16-bit
EMG resolution	12-bit
EMG signal noise	3μV
Battery	155mA 3.7 LiPo rechargeable (enables up to 8h in continuous operation)
Medical grade charger	guarantees galvanic isolation
Size	28x70x12mm
Weight	25g

The device was then turned on and connected via Bluetooth to a computer with OpenSignals software and the subject was asked to perform some basic movements such as raising the hand in order to confirm that it was working as intended. When the subject was ready, the recording of data via OpenSignals was started and the session could begin. (Jonsson, 1988). Also, during the experiment both the traditional and the proposed new ergonomically designed workstation were used Trigno Research+ (Delsys, SAD) equipment used to record, measure and wirelessly transmit sEMG signals from the Trigno EMG sensor to the base station (Jonsson, B. G. et al., 1988). The equipment consists of a base station, an EMG sensor, a laptop on which the software is installed, which has the role of collecting, processing and analyzing the data. The main specifics are that the Trigno Avanti™ sensors support a low-noise, high-fidelity sensing circuit for detecting EMG signals when muscles contract from the surface of the skin. The maximum distance for successful data transmission between the sensor and the base was 10 meters. Trigno Avanti™ sensors were placed on the trapezius muscles on the subject's neck on the left and right side. Maximum muscle contraction was taken into account when placing the sensor itself. The recorded signals will be analyzed in real time using LabChart software. Figure 2. shows the Trigno Research+ equipment used during the experiment - a box as a base station and EMG sensors

Figure 2. Trigno Research+ equipment

Also, as part of the research, an EEG cap with an amplifier was placed on the head of the subjects as part of a separate experiment that was conducted in order to monitor the brain activity of the subjects. In the experiment, 3 IP cameras were used, which had the role of monitoring the positions of the workers' bodies from three different positions - one camera was placed in front of the workers, and the remaining two cameras were on the left and right sides of the workers.

Experiment scenario

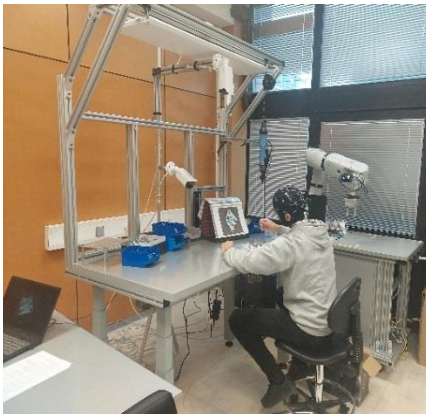
The experiment was conducted twice in two different scenarios - ergonomic and non-ergonomic. In both scenarios, the experiment consisted of two sessions lasting 1.5 hours (90 minutes) each, during which the respondents performed the activities of assembling electronic components according to predetermined rules. The participants assembled the finished product by inserting blue wires from the container into a part made of plexiglas and closing the switch according to the diagram displayed on the monitor (in the ergonomic scenario) or according to paper instructions (in the non-ergonomic scenario). Participants in the experiment first received initial instructions, and after that, they performed assembly activities for 15 minutes in order to practice.

Between sessions, participants had a short break of 15minutes. Thus, including the time necessary to prepare the experiment, set up the equipment and prepare the subject. The experiment in the ergonomic scenario and the non-ergonomic scenario were not performed on the same day.

In the non-ergonomic scenario, participants perform assembly work activities at a traditional workstation (Picture 3.). In this scenario, conditions from a real industrial environment were simulated i.e. 2D schematics and 3D images of the participants assembling the final product were displayed in paper format on a binder that was placed on a stand to the right of the subject. Additional difficulties encountered in this type of scenario are related to the constant turning of sheets of paper showing 2D schematics and 3D images after each completed product.

In the non-ergonomic scenario, the Plexiglas parts were located in a box next to a traditional assembly workstation so that subjects had to bend over to reach this part. The parts and components necessary to perform the assembly activities were placed outside the green zone and the subjects had to stretch their body to reach them. Also, the problem was that there were wires of various colors in the containers and not only the blue wires that were used during the experiment, which made it even more difficult for them to carry out the activity.

After finishing the part, the subjects bent down to drop the finished product into the box next to the table. In the non-economic scenario participants were exposed to noise while performing activities.



Picture 3. Participant performs an experiment on a traditional assembly workstation

The experiment in an ergonomic scenario was realized on a proposed innovative modular assembly workstation, which is designed in accordance with the lean principles, main ergonomics principles and adapted to the needs and requirements and individual characteristics of the operator (Picture 4.). Anthropometric properties and measurements are essential factors to consider when designing a new workstation. Anthropometry is the scientific study of the measurements and proportions of the human body, and it plays a critical role in designing workstations that are ergonomic and safe for workers (Wojcikiewics, 2003). In order to design a workstation that is suitable for at least 90 percent of male and female body sizes, designers must take into account a variety of anthropometric factors, such as body height, weight, arm length, and leg length.

At the new workstation, the subjects had the possibility to adjust the height of the table and chair to match their height, and the control zone was adjusted to the individual reach of the dominant hand and individual preferences. In new assembly workstation all components storage containers are arranged taking into account that the zones of the handling area are different for each person to reduce bending, straining and stretching of the body. The flexible arrangement of containers for storing parts and components on the newly designed workstation provides the ability to change the layout and organization of the work environment and adapt to the individual reach of the examinee. At the proposed assembly workstation, respondents perform activities in a combined (sitting and standing position) without feeling tired, exhausted and physically strained.

In the ergonomic scenario, the participants performed assembly activities based on information about 2D schemes and 3D images that they received from the touchscreen screen in front of them. Also, in the egonomic scenario, the Plexiglas parts were placed on the right side of the subject within the golden zone to avoid unnecessary bending of the body. The container with the blue wires used during the experiment was placed in accordance with lean and ergonomic principles to avoid unnecessary reaching and stretching of the body. The experiment was performed in a idealy laboratory conditions.

Picture 4. Participant performs an experiment on a proposed modular assembly workstation

Using innovative EMG technologies, muscle activity was measured in real time during both scenarios individually. Before placing the MuscleBAN device, the skin around the subject's upper trapezius muscles was first cleaned and disinfected, and then a gel for isotonic recording electrodes was applied to it. During the experiment GEL101A electrode paste was used, which is specially formulated with 0.5% saline added to a neutral base to create an isotonic, 0.05 molar NaCl, electrode paste. Unlike agar or saline pastes, this paste has a virtually unlimited shelf life, making it suitable and efficient to use in long-running experiments (ELECTRODE GEL, ISOTONIC, n.d.). After the gel has been applied and any excesses of it removed, the MuscleBAN BE EMG device was placed and secured via strong tape to both sides of the trapezial muscles.

3. Results and discussion

Figures 5. and 6. show the raw signals of monitoring muscle activity on the left and right hand of one subject using the MuscleBAN BE device and Trigno Research+ equipment

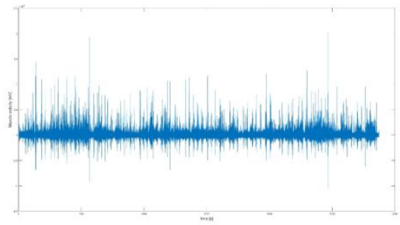


Figure 5. Raw sEMG signal using the MuscleBAN BE device in non-ergonomic scenario (left hand)

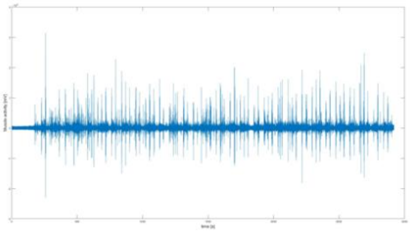


Figure 6. Raw sEMG signal using the MuscleBAN BE device in non-ergonomic scenario (right hand)

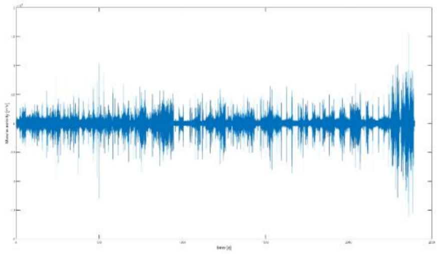


Figure 7. Raw sEMG signal using the MuscleBAN BE device in ergonomic scenario (left hand)

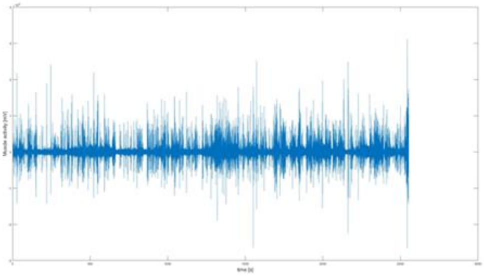


Figure 8. sRaw EMG signal using the MuscleBAN BE device in ergonomic scenario (right hand)

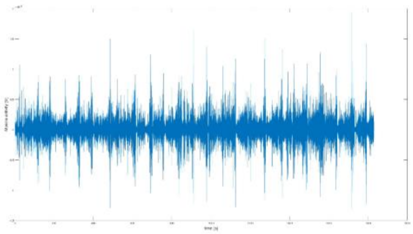


Figure 9. Raw sEMG signal using the Trigno Research+ equipment in non-ergonomic scenario (left hand)

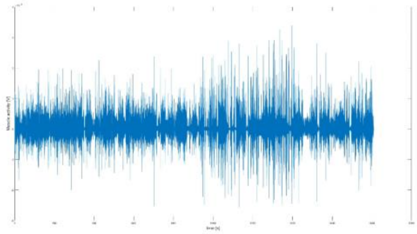


Figure 10. Raw sEMG signal using the Trigno Research+ equipment in non-ergonomic scenario (right hand)

Raw s EMG signals are the basis for conducting time analysis, frequency analysis and feature analysis in the following period.

4. Conclusion

In the context of Industry 4.0, a human-centered workplace is one that incorporates advanced technologies and digital systems in a way that supports workers and enhances their capabilities, rather than replacing them or making their jobs more difficult. By leveraging the power of new technologies, organizations can improve their occupational safety and health practices and create safer and more pleasant workplaces.

Workers who perform repetitive and tedious activities at a traditional assembly workstation for long periods of time are at risk of developing musculoskeletal disorders, such as carpal tunnel syndrome, tendinitis, and back pain. These conditions can cause physical discomfort and pain for workers, and can lead to reduced productivity, absenteeism, and even long-term disability.

Monitoring muscle activity and implementing preventive activities in order to reduce the occurrence of musculoskeletal disorders and other occupational diseases to which workers who perform assembly activities are exposed is very important. Using EMG equipment, the electrical activity of muscles during contraction and relaxation was measured for assessing the load and strain on the muscles. By analyzing the EMG signals, it can be determined whether the muscles are being overloaded or strained.

The directions of future research are related to the detailed analysis of data obtained by monitoring muscle activity in real time in order to and observation assembly activities by video-camera in order to optimize the worker's body posture and avoid uncomfortable or unsafe postures and to improve helath and safety of workers who perform repetitive, tiring and monotonous assembly activities for a long period of time in an unergonomic position. In this way, the risk of musculoskeletal disorders will be reduced and the overall performance of the system will be improved.The results will be compared with the results obtained using the ergonomic methods RULA and REBA.

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Marija Savković
Faculty of Engineering,
University of Kragujevac,
Serbia
marija.savkovic@kg.ac.rs

Miloš Petrović
University of Belgrade
School of Electrical
Engineering,
University of Kragujevac,
Serbia
petrovic.milos@etf.bg.ac.rs

Carlo Caiazzo
Faculty of Engineering,
University of Kragujevac,
Serbia
carlocaiazzo@fink.rs

Marko Đapan
Faculty of Engineering,
University of Kragujevac,
Serbia
djapan@kg.ac.rs

Arso Vukićević
Faculty of Engineering,
University of Kragujevac,
Serbia
arso_kg@yahoo.com