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Spoštovani bralci revije Journal of energy technology (JET)

Podatki kažejo, da se za transport v globalu porabi približno 25 % od celotne porabljene količine energije. Največji porabnik energije v transportu je cestni potniški promet, sledijo tovorni, letalski, ladijski. Kljub energetsko učinkovitejšim in ekološko sprejemljivejšim energetskim sistemom z večanjem števila prebivalcev in naraščanjem kupne moči poraba energije v svetu narašča. Trenutno energija dizelskega goriva, kerozina in bencina poganja skoraj 90 % vseh energetskih transportnih sistemov. Vse druge oblike energije, uporabljene v transportu, so procentualno zelo majhne. Z upoštevanjem dejstva, da bo ogljikovodikov v prihodnosti zmanjkalo, ter dejstva pogostejših ekoloških težav, je potrebno še bolj intenzivirati energetsko učinkovitost transportnih naprav in pričeti uporabljati ekološko sprejemljivejše naprave. Zagotovo bi bila prava pot ureditev transporta po zgledu npr. Nizozemske, saj večino poti po mestih ljudje opravijo s kolesi. Verjamem, da bi se na ta način in seveda v povezavi s sodobnimi vlaki, uporabo električnih vozil, intenzivno izrabo obnovljivih virov ter alternativnih energetskih sistemov za proizvodnjo električne in toplotne energije močno zmanjša poraba energije in izraba ogljikovodikov.

V povezavi z zgoraj omenjenimi temami v tej številki revije objavljamo zanimiv članek o posodobitvi ultralahkega letala.

Jurij AVSEC
odgovorni urednik revije JET

Dear Readers of the Journal of Energy Technology (JET)

According to the relevant data, transport consumes about 25% of the total global amount of energy consumed. The biggest consumer is road passenger transport, followed by road freight, aviation, shipping, etc. With the growing population and increasing purchasing power of people, energy consumption in the world will increase, despite the efforts of manufacturers of energy-efficient and environmentally-friendly energy systems. At the moment, diesel, kerosene, and gasoline power almost 90% of all energy transport systems. All other forms of energy used in transport remain very small. Due to the expectations that fossil fuels will run out in the future, and increasingly intense environmental problems, it is necessary to intensify the energy efficiency of transport equipment and start using more environmentally friendly equipment. The arrangement of transport in the Netherlands points to a possible solution for the near future. Most of the city transportation is with bicycles, which are a highly energy-efficient transport medium. In conjunction with modern trains and other means of transport, the intensive use of electric vehicles, the use of renewable sources and alternative energy systems for the production of electricity and heat, I believe that energy consumption and the use of hydrocarbons can be greatly reduced.

In a related note, this issue of JET contains an article about the renovation of an ultralight aircraft.

Jurij AVSEC
Editor-in-chief of JET

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Journal of Energy Technology

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THE PLC CONTROL OF AN ELECTRICAL SYSTEM CONSISTING OF AN ELECTROMAGNETICALLY SLIDING BRAKE AND COUPLING

UPORABA PLC KRMILNIKA PRI VODENJU ELEKTRIČNEGA SISTEMA SESTAVLJENEGA IZ ELEKTROMAGNETNE DRSNE ZAVORE IN SKLOPKE

Georgel Gabor[ℜ], Adrian Traian Plesca[1]

Keywords: Electromagnetically sliding couple, electromagnetically sliding brake, PLC, PROFIBUS, Variable Frequency Converter, Industrial communication

Abstract

This paper describes an electrical system consisting of electrical sliding coupling driven by a 3 phase electric motor and electric sliding brake. A frequency converter provides control of the motor. Furthermore, the communication between PLC and frequency converter is done using PROFIBUS communication. The data are displayed on a SIEMENS HMI display. The goal is to control the electrical sliding coupling, which is mechanically connected to the electrical sliding brake.

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Povzetek

V članku je opisan električni sistem, sestavljen iz električnega drsnega sklopa, ki ga poganja 3 fazni električni motor in električne drsne zavore. Vodenje motorja se izvaja s pomočjo Siemensovega frekvenčnega pretvornika. Komunikacija med PLC krmilnikom in frekvenčnim pretvornikom je izvedena s pomočjo Profibus protokola. Podatki so prikazani na Siemensovem HMI vmesniku. Cilj predstavlja nadzorovanje električne drsne sklopke, ki je mehansko povezana z električno drsno zavoro.

1 INTRODUCTION

In the modern world, Programmable Logic Controllers (PLC) are significant components in industrial automation and control systems. They can be integrated into an electrical system to obtain desired results. The electrical sliding couple makes the connection between a 3-phase asynchronous motor drive and the working machine shaft. The couplings are the switching apparatus of mechanical power with remote control. The couplings that make the motor halt are called brakes. The mechanical forces of the couplings and brakes represented by electromagnetic forces are electromagnetic couplings and electromagnetic brakes.

In the past, the system consisting of an electrical sliding brake and coupling was controlled by electrical components, for example, the Autotransformer (ATR), to vary the excitation current on the electrical coupling. Nowadays, the PLC that contains Digital Inputs, Digital Outputs, Analog Inputs and Analog Outputs communicating with dimmer in Master-Slave configuration can accomplish such tasks. By including the Variable Frequency Converter and HMI in the hardware, the system becomes more reliable and flexible.

The main advantages of using an electric sliding coupling and electric sliding brake are a shockless start, speed control, and torque control for the winding machines, which must maintain the stretching force at a constant level while the diameter is increasing.

2 INDUSTRIAL COMMUNICATIONS

PROFIBUS-DP (Decentralized Peripherals) is the most suitable communication system for high speed, low time-consuming and low-cost data transfers. PROFIBUS (PROcess FIeld BUS) is a standard for field bus communication used for process automation *[1-7].* The length of the transmission line influences the rate of transmission. PROFIBUS-DP communication speed can vary from 9.6kbps to 12Mkbps, and the transmission distance ranges from 100 m to 1,200 m. PROFIBUS-DP is designed for fast data exchange between sensors-actuators and automation systems integrated into programmable logic controllers, *[2].* In the current test case, the PROFIBUS communication is implemented using a SIEMENS communication module CM 1242-5 connected to the CPU. PROFIBUS communication with the S7-1200 CMs is based on the PROFIBUS DP-V1 protocol. The variable frequency drive contains PROFIBUS card inserted in the slot drive. It has a wide usage area in automation systems, and a variety in terms of communication, including FMS (Fieldbus Message Specification), PA (Process Automation) and DP (Decentralized Periphery), *[3].*

In the configuration of the test bench, the PLC is the master and has a communication processor CP1243-5 PROFIBUS CP Master and the frequency converter EATON SVX 9000 is the slave. The communication between the PLC and HMI is PROFINET, as shown in Figure 1.

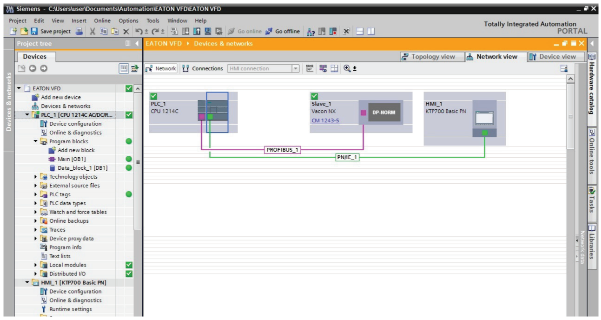

Figure 1: *Hardware configuration*

The devices that support the PROFIBUS protocol may have different characteristics. This includes the number of I/O signals, diagnostic messages or bus parameters such as baud rate and time monitoring. These parameters can vary for each device type and vendor and normally are usually described in the user manual. To implement a simple Plug and Play configuration for PROFIBUS devices, GSD files are defined to describe the communication features of the devices. These are electronic device data sheets and are called General Station Description (GSD) files, which allows easy configuration of PROFIBUS networks with devices from different types of manufacturers, *[5].*

The communication with Human Machine Interface or HMI is realised by PROFINET. HMIs can be designed with different types of interfaces: with touch display, push buttons and touch display, mobile device or a computer with a keypad. HMI screens show the user the information from the process, and the operator can interact with the machine by changing the values of the parameters. The HMI screen contains buttons to Enable/Disable the drive, Run, Stop and output field for monitoring the current values of the voltage, current, frequency. In the trend section on the screen, the variation of the frequency can be visualized in Hz or the current in Amps.

The Variable Frequency Drive (VFD) industry is growing fast, and its applicability is in a variety of industrial processes. Variable Frequency Drives change the speed of the motor by increasing/decreasing the voltage and frequency of the power supplied to the motor. To keep proper power factor and reduce excessive heating of the motor, the volts/hertz ratio must be fulfilled, *[6].*

The PROFIBUS DP option board for 9000X Drive from Eaton Electrical makes the connection between the variable frequency drive and PLC. The data are transferred between Master and Slave through input/output field. The communication card has a PROFIBUS address that can be adjusted from the front panel. The process data field is used to control the device (for example Run, Stop, Set point) and reading the values as Output frequency, Actual current, Actual Voltage.

3 ELECTRICAL SLIDING COUPLING AND ELECTRICAL SLIDING BRAKE

The electrically sliding couple, also called clutch, is used in driving compressors, ventilators, pumps, starting and braking system. In Figure 2, the main components of the electrical coupling are indicated. The rotor of an electrically sliding coupling is mechanically connected to the rotor of the electrical motor. When the motor is started, the rotor (1) starts to spin with constant rpm. The excitation current in the stator (2) produces a magnetic field.

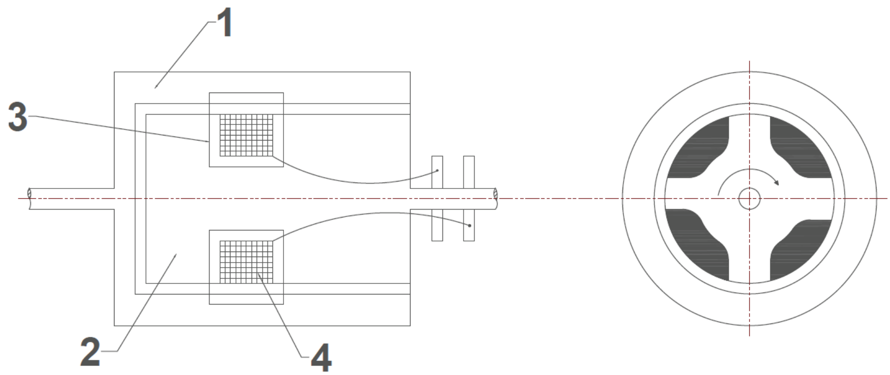

Figure 2: *Electrical sliding coupling*

The 3-phase electrical motor is mechanically connected to the electrical sliding coupling, assuring a smooth start for the electrical sliding brake. The electrical sliding coupling has similar functionality as an asynchronous electrical motor. The difference is the rotating magnetic field is created by the stator and not by the current induced by the rotor as in case of an electrical motor.

When the coupling is a supplied power, the excitation current produces magnetic flux that influences the coupling torque. The balance of motor torque and coupling torque will establish again at the low speed of the motor drive.

The electrical sliding couple is connected to the DC power supply through a transformer and diodes bridge. The voltage adjustment is made with an electronic dimmer that accepts 0-10V DC input from PLC Signal Board Analog Output. For different steps of the input current, the output results in different DC step voltage than Table 1. Table 1 shows the different steps for the input current as well as the voltage on primary and secondary of the transformer.

Table 1: *Electrical sliding coupling parameters*

No.	Electrical sliding couple DC power supply			
	Ic[mA]	*Up[V]*	*Us[V]*	*Uscc[V]*
1.	100	25	3	3
2.	200	48	7	6.2
3.	300	70	11	9.2

No.	Electrical sliding couple DC power supply			
	Ic[mA]	*Up[V]*	*Us[V]*	*Uscc[V]*
4.	400	89	14	12
5.	500	109	17	15
6.	600	129	21	18
7.	700	147	24	20.5
8.	800	169	27	23.5
9.	900	189	30	26.5
10.	1000	210	34	29.5

The electrical sliding brake is also connected to the 230V power supply through a transformer and bridge diode. For different steps of the input current, the output results in different DC step voltage, as shown in Table 2.

Table 2: *Electrical sliding brake parameters*

No.	Electrical sliding brake DC power supply			
	If[mA]	*Uap[V]*	*Uas[V]*	*Uscc[V]*
1.	100	42	3	2.37
2.	200	76	6	4.9
3.	300	106	10	7.3
4.	400	137	12	9.7
5.	500	167	15	12
6.	600	199	18	14.5
7.	700	230	21	17

4 EXPERIMENTAL TEST BENCH

The test bench (Fig. 3) consists of a 3-phase asynchronous motor, power 1.5kW, 1450 rpm, delta 230V, 6.4A and power factor 0.82 was used. The motor is mechanically fixed to an electromagnetically sliding brake through an electromagnetically sliding couple. The motor is connected to the PROFIBUS network structure with an EATON SVX 9000 frequency converter, Drive 3AC, 0.75HP, 240V, 3.7A.

The automation system has a Siemens Programmable Logic Controller (PLC) with SIMATIC S7-1200, CPU 1214C, AC/DC/relay, onboard I/O: 14 digital inputs 24 VDC; 10 digital outputs on relay 2A; 2 analogue inputs, power supply module: AC 85-264 V AC at 47-63 Hz, program/data memory 100 KB. The communication over PROFIBUS network is assured by communication processor communication module CM 1243-5 for connection of SIMATIC S7-1200 to PROFIBUS as DP master module.

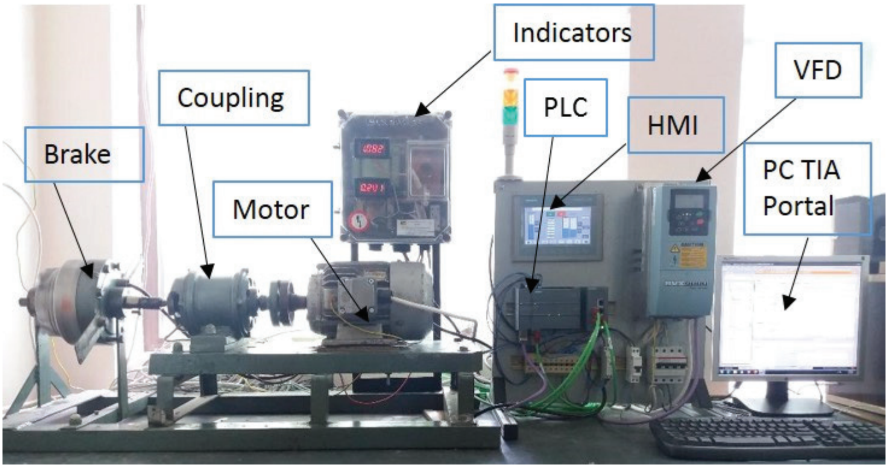

Figure 3: *Test bench*

The software used for configuration of the automation system is SIEMENS TIA Portal V13. It comprises Step 7 software for PLC programming and WinCC for HMI design. STEP 7 (TIA Portal) is the engineering software for configuring the SIMATIC controller families S7-1200, S7-1500, S7-300/400 and software controllers (WinAC). WinCC (TIA Portal) is engineering software for configuring SIMATIC Panels, SIMATIC Industrial PCs, and Standard PCs with the WinCC Runtime Advanced or the SCADA System.

The PLC programming includes the configuration of PROFIBUS communication between PLC and variable frequency drive, hardware configuration, and the program. The data between PLC and HMI are stored in Data Blocks.

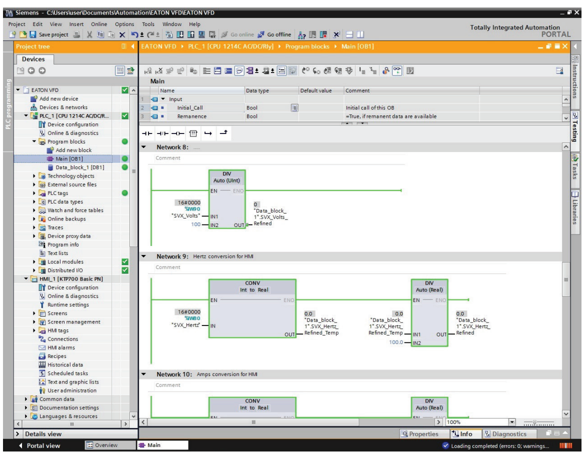

Figure 4: *PLC programming*

To vary the excitation current on the electrical sliding brake, the analogue output of the Siemens signal board is used. Signal boards are connected directly to the front of the SIEMENS CPU. They can be used where space is limited or if only a few additional inputs/outputs are required. While increasing the brake current by INC and DEC buttons, the torque of the brake will increase obtaining the family of the curves in Figure 5. The force is measured by an electronic scale.

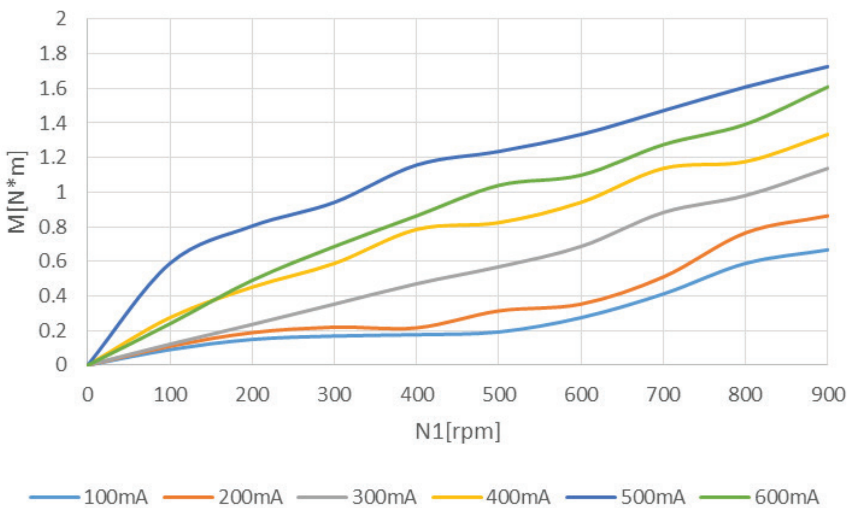

Figure 5: *Torque vs RPM*

5 CONCLUSIONS

Testing of the speed and torque of electrical system has been performed in this study by using a Profibus industrial automation network. This study has shown that the control and monitoring of an electrical system by using PROFIBUS yields high performance. This situation has been realized with the data obtained from the test bench. The graphics show the dependency of the torque by excitation current of the coil of the electrical sliding brake for different test cases. This experiment can be improved by controlling the current PLC technology over the Internet.

References

[1] *PROFIBUS Standard Part 1 and 2, DIN 19 245,* German Institute of Normalization, 1995

[2] **Hongjun Chen, Xiaohua Zbang, Xuerui Zbang** *Application of Profibus to industrial automation",Siemens Automation Training Center*, Harbin (SA TCH), Department of Electrical Engineering, Harbin Institute of TechnologyHarbin, 150001, P. R. China, 1998

[3] **C. Yılmaz and Y. Korkmaz, Y. Sönmez and L. Bulut, M. Fatih Işık**: *Controlling of a 3-Phased Asynchronous Motor over Profibus*, International Journal of Electronics and Electrical Engineering Vol. 4, No. 1, February 2016

[4] *Specification for PROFIBUS Device Description and Device Integration*, Volume 1: GSD, Order No. 2.122, Version 5.1, July 2008

[5] *Specification for PROFIBUS Device Description and Device Integration* , Volume 1: GSD, Order No. 2.122, Version 5.1, July 2008

[6] **Tamal Aditya, Gyan:** *Research to study Variable Frequency Drive and its Energy Savings, Vihar School of Engineering and Technology,* International Journal of Science and Research (IJSR)*,* India Jaipur-302025, India, Volume 2 Issue 6, June 2013

[7] **Hongjun Chen, Xiaohua Zbang, Xuerui Zbang:** , *Application of Profibus to Industrial Automation*, International Journal of Electronics and Electrical Engineering Vol. 4, No. 1, February 2016, Research article, IFAC Proceedings Volumes, Volume 31, Issue 25, September 1998, Pages 157-161

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ENERGY EFFICIENCY ANALYSIS IN MOBILE HYDRAULICS

ANALIZA ENERGETSKE UČINKOVITOSTI V MOBILNI HIDRAVLIKI

Ervin Strmčnik[1,ℜ], Damjan Konovšek[2]

Keywords: energy efficiency, mobile hydraulics, optimization

Abstract

The primary purpose of this paper is to estimate possible energy and cost savings in the optimization of mobile hydraulics. A gerotor is a low-speed, high-torque hydraulic motor, which is very rarely described in the literature and often use in mobile hydraulics. In this paper, the total efficiency of the hydraulic motor was investigated. The influence of the size of the holes in the valve plate on the total efficiency of the gerotor was analysed. The total efficiency is the most important and prominent information about the energy conversion of hydraulic components, such as hydraulic motors and pumps. The operation of a gerotor is briefly described as well as some equations for the determination of displacement and efficiency. The results show that there is a correlation between the size of holes in the valve plate and the total efficiency of the gerotor. Furthermore, a very high total efficiency was obtained with the hole size of Φ6.3 mm. In that case, the total efficiency was on average 16.1% higher in comparison to the total efficiency when the hole size was Φ5.5 mm. It plays a significant role in possible reductions in energy cost. Energy analysis and cost estimation were conducted.

Povzetek

Glavni namen raziskave je bil oceniti energetske in stroškovne prihranke, ki so posledica optimizacije v mobilni hidravliki. Gerotor je počasno vrteč hidravlični motor za premagovanje velikih momentov.

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Takšen hidravlični motor je redko opisan v literaturi, ampak pogosto uporabljen v praksi. V prispevku je raziskana možnost povečanja skupnega izkoristka takšnega hidravličnega motorja zaradi spreminjanja velikosti lukenj v ventilski plošči. Skupni izkoristek je merilo, kako učinkovita je pretvorba hidravlične energije v mehansko delo. V prispevku je predstavljeno delovanje hidravličnega motorja in postopek določitve skupnega izkoristka. Rezultati so pokazali, da velikost lukenj pomembno vpliva na skupni izkoristek. Pri velikosti lukenj Φ6.3 mm je bil skupni izkoristek kar 16.1% večji kot pri velikosti lukenj Φ5.5 mm. To je pomembo dejstvo, ki nas je spodbudilo, da smo opravili energetsko analizo in ocenili možne prihranke, ki bi jih lahko dosegli.

1 INTRODUCTION

Energy efficiency is specified by the European Union (EU) as a key driver of the transition toward a low-carbon society, *[1]*. The Republic of Slovenia follows the European legislation related to the new rules in the energy market, *[2].* A new energy concept in Slovenia was proposed *[3]*, *[4].* Energy technology is one of the most critical topics in mobile hydraulics, where energy savings play a critical role in cost reduction. The rapid development of mobile hydraulics in recent years has contributed many innovations and improvements in the field. One of the groups of hydraulic components is the hydraulic motor group. Hydraulic motors convert hydraulic energy into mechanical energy. The most crucial measure of performance of a hydraulic motor is the total efficiency. In this paper, the results of the measurement of a slow rotation orbital hydraulic motor are presented. There are many factors that influence the hydraulic motor's performance. The influence of the size of the holes in the valve plate was investigated. The holes are essential to the inlet and outlet flow of the fluid. Fluid takes care of the relative movement of the gear pair and lubrication of the main parts of the hydraulic motor. In the research, we have determined that the diameter of the holes in the valve plate influences hydraulic motor performance significantly. With the right choice of hole diameter, we can raise the total efficiency on average around 16.1%. The above-described hydraulic motor has a large carbon footprint; consequently, care must be taken to continuously develop reductions in energy demand.

The paper is structured as follows: in the introduction, the objective and the purpose of the research are described. Section 2 covers the literature review. More details of the hydraulic gerotor motor are described in Section 3. The methodology is explained in Section 4. The results are presented in Section 5. In Section 6 key findings of the research are summarized. At the end is a list of references and a nomenclature explanation.

2 LITERATURE REVIEW

In the relevant literature, there are few scientific papers that deal with hydraulic gerotor motors with a floating outer ring. There are many factors that influence the performance of the gerotor. The viscosity, viscosity index, high-shear viscosity, piezo-viscosity, and shear stability of prototype fluids have been characterized in the research of the influence of fluid properties on the total efficiency of low-speed, high torque hydraulic motors, *[5].* A significant influence on the total efficiency of hydraulic motor or pump is the geometry of the gear pair, *[6]*, *[7]*, *[8].* A kind of deep analysis of multiple performance attributes and structural design of the gerotor motor has been extensively investigated through multi-objective optimization design of the gerotor motor, *[9].* Pressure distribution within a gerotor and some other physical quantities were analysed through a CFD model for an orbital gerotor motor, *[10].* A CFD analysis aids in understanding the physics of a gerotor's operation and enables the rapid development of new hydraulic motors, *[11].* The total efficiency is very much related to losses. Experimental and torque losses in gerotors were investigated in the case of hydrostatic machines, which are complex fluid dynamic systems due to their intricate and partially unknown dynamics, *[12].* Some losses are related to tribological behaviour. The most important are friction, *[13]*, and wear, *[14]*, *[15].*

3 HYDRAULIC MOTOR - GEROTOR

The hydraulic gerotor motor consists of thirty different parts. The maximum diameter is Φ174 mm, whereas the maximum dimension is the length of the gerotor (250 mm). It has a mass of around 20 kg. Its working pressure is up to 350 bar. The inner rotor has 9 teeth, and the outer ring has 10 teeth (Figure 1a). They together constitute 10 lobes. On Figure 1b, there are twenty holes, which are part of the valve plate. The first hole has the mark L1 and the last one L20. Odd numbers represent holes that are connected with the high-pressure zone, and even numbers represent holes that are linked to the low-pressure zone. As operators, we can change the low and high-pressure zones with the control valve.

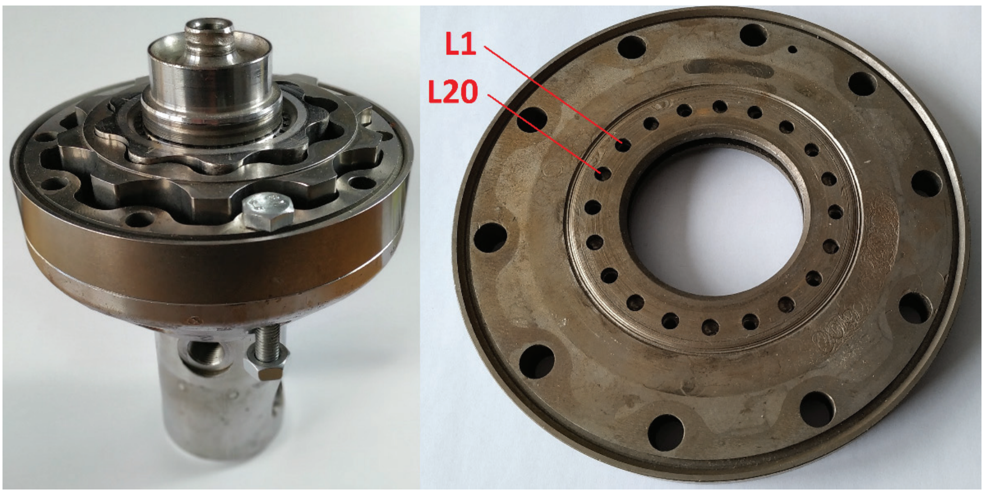

Figure 1: *(a) Gerotor Hydraulic motor (Φ174 mm × 250 mm), (b) valve plate (Φ174 mm × 15 mm)*

Gerotor displacement volume is essential information that helps determine the volumetric and the hydraulic-mechanical efficiency of the hydraulic motor. Standard ISO 8426, *[16]*, proposes the measurement of volume flow rate with different pressure differences, whereas the speed of the shaft of the hydraulic motor is a constant value. We have to determine the volume flow rate for $\Delta p = 0$. This can be done graphically with the help of the method of least squares, as shown in Equation 3.1.

$$V_i = \left\{ \left(\frac{1}{k} \sum_{i=1}^{k} Q_i \right) - \left[\frac{\frac{1}{k} \sum_{i=1}^{k} (\Delta p_i Q_i) - \frac{1}{k^2} \left(\sum_{i=1}^{k} \Delta p_i \right) \left(\sum_{i=1}^{k} Q_i \right)}{\left(\frac{1}{k} \sum_{i=1}^{k} \Delta p_i^{\,2} \right) - \left(\frac{1}{k} \sum_{i=1}^{k} \Delta p_i \right)^2} \right] \left(\frac{1}{k} \sum_{i=1}^{k} \Delta p_i \right) \right\} \frac{1}{n} \tag{3.1}$$

The most important fact related to energy consumption of the hydraulic component is efficiency. It represents the ratio between the useful output to the total input, in energy terms. The total efficiency of the hydraulic motor is the ratio between output mechanical energy ($P_{izst,HM}$) and input hydraulic energy ($P_{vst,HM}$) as shown in Equation 3.2.

$$\eta_{s,\,HM} = \frac{P_{izst,\,HM}}{P_{vst,\,HM}} \tag{3.2}$$

Mechanical energy ($P_{izst,HM}$) is dependent on rotational speed (n_{HM}) and torque (M_{HM}) as shown in Equation 3.3.

$$P_{izst,\,HM} = 2 \cdot \pi \cdot n_{HM} \cdot M_{HM} \tag{3.3}$$

Hydraulic energy ($P_{vst,HM}$) is defined by flow rate ($Q_{vst,HM}$) and the pressure difference between inlet pressure ($p_{vst,HM}$) and outlet pressure ($p_{izst,HM}$); see Equation 3.4.

$$P_{vst,\,HM} = Q_{vst,\,HM} \cdot \left(p_{vst,\,HM} - p_{izst,\,HM} \right) \tag{3.4}$$

Considering Equations 3.2, 3.3, and 3.4, we get Equation 3.5.

$$\eta_{s,\,HM} = \frac{2 \cdot \pi \cdot n_{HM} \cdot M_{HM}}{Q_{vst,\,HM} \cdot \left(p_{vst,\,HM} - p_{izst,\,HM} \right)} \tag{3.5}$$

In a very similar way, we can calculate the hydraulic-mechanical efficiency as shown in Equation 3.6.

$$\eta_{hm,HM} = \frac{M_{HM} \cdot 2\pi}{\left(p_{vst,HM} - p_{izst,HM} \right) \cdot V_{HM}} \tag{3.6}$$

The volumetric efficiency of the hydraulic motor is defined by rotational speed (n_{HM}), displacement (q_{HM}), and flow rate ($Q_{vst,HM}$); see Equation 3.7.

$$\eta_{v,\,HM} = \frac{n_{\mathrm{HM}} \cdot V_{\mathrm{HM}}}{Q_{vst,\,HM}} \tag{3.7}$$

In general, the total efficiency is the result of multiplication of the hydraulic-mechanical efficiency and the volumetric efficiency (Equation 3.8).

$$\eta_{s,\,HM} = \eta_{hm,HM} \cdot \eta_{v,\,HM} \tag{3.8}$$

4 METHODOLOGY

Within the research, the influence of the size of the holes in the valve plate on the hydraulic motor characteristics was investigated. According to the previous research activities, we decided to observe a hydraulic motor at a rotational speed of 15 min^{-1} and at three different pressure differences: 160 bar, 200 bar, and 240 bar. Within the broad set of the measurement activities, we took into account recommendations and guidelines from different international standards; we would like to emphasise the importance of the international standard ISO 8426, *[16]*, as well as other standards which are related to different types of the hydraulic motor efficiency. Our main purpose was to determine hydraulic motor displacement volume and total, volumetric, and the hydraulic-mechanical efficiency of the investigated hydraulic motor. The original diameter of holes in the valve plate was Φ5.5 mm (Scenario 0). Holes were later increased to Φ6.3 mm (Scenario 1) and Φ6.9 mm (Scenario 2).

Energy efficiency analysis was made according to the data, downloaded from the Statistical Office of Slovenia. A price for business consumers was calculated based on the price average for 2017, *[17].* It was €0.075/kWh in Slovenia.

5 RESULTS

5.1 The total efficiency

The most important results of the research activities are presented in Figure 2, which shows a relationship between the total efficiency and size of the holes in the valve plate. Different colours represent different hole sizes (different scenarios). There is pressure difference (range: from 160 bar to 240 bar) on the x-axis and the total efficiency (range: 0%-45 %) on the y-axis. The height of a column represents a value of the total efficiency in a specific measured point. The greater the height of the column, the greater the total efficiency of the hydraulic gerotor motor. The highest total efficiency was obtained in Scenario 1 (hole: Φ6.3 mm) and the lowest in Scenario 2 (hole: Φ6.9 mm). In other words, the highest total efficiency was obtained with the hole diameter of Φ6.3 mm. The additional increase of the hole diameter had a negative influence on the total efficiency.

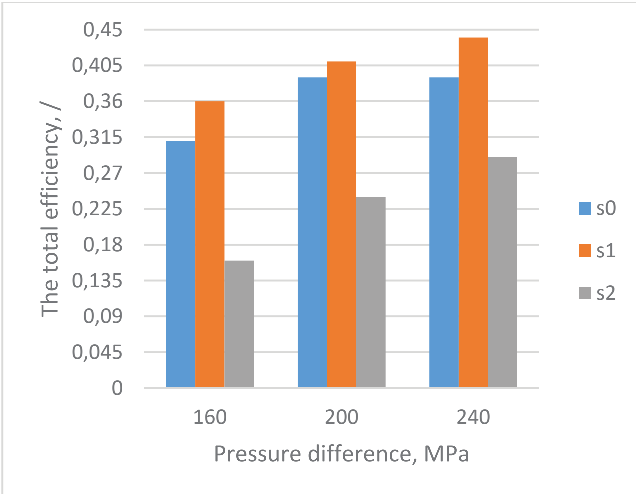

Figure 2: *The total efficiency of the gerotor (operating point: n = 15 min^{-1})*

5.2 Energy efficiency analysis

Columns in Figure 3 represents cost per year for three different scenarios. As shown, Scenario 1 (in comparison with Scenario 0=initial scenario) leads to a cost reduction from €1544 to €1295 per year for a pressure difference of 160 bar, from €1923 to €1824 per year for a pressure difference of 200 bar, and from €2329 to €2031 per year for a pressure difference of 240 bar. Regarding the calculation, Scenario 2 is worse than scenario 0. There is a cost increase from €1544 to €2291 per year for a pressure difference of 160 bar, from €1923 to €2663 per year for a pressure difference of 200 bar, and from €2329 to €2927 per year for a pressure difference of 240 bar. On average, it is possible to save around €215 per year if optimization is performed wisely.

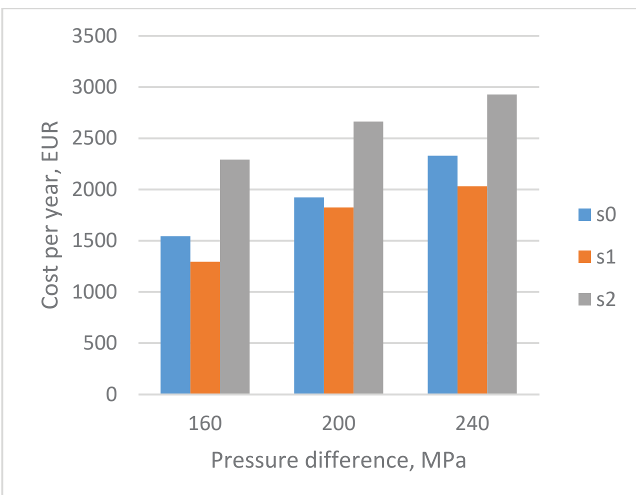

Figure 3: *Cost per year for three different scenarios*

Cost savings for three different scenarios are presented in Figure 3. In Scenario 1 and a pressure difference of 240 bar, it is possible to reach €299 of saving with Scenario 0. In the worst case, when Scenario 2 was analysed, losses between around €600 and €750 may occur.

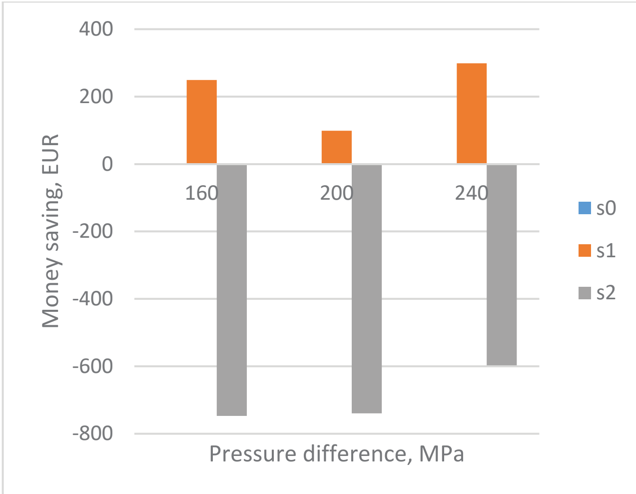

Figure 3: *Money saving for three different scenarios*

6 CONCLUSION

An energy efficiency analysis in mobile hydraulics was discussed in this paper. The conclusion of this study can be summarized as follows:

- The diameter of holes in the valve plate influences the total efficiency of the hydraulic gerotor motor;
- Very high total efficiencies were reached with a hole diameter of Φ6.3 mm;
- The highest total efficiency was on average 16.1% higher than the total efficiency of the original hole size. It means that a hydraulic motor with the hole diameter of Φ6.3 mm in the valve plate has on average 16.1% better operation characteristic in every measured point than a hydraulic motor with the hole size of Φ5.5 mm in the valve plate;
- Energy efficiency analysis showed that it is possible to save around €215 per year on average due to optimization.

References

[1] **European Commission, Climate Action, Roadmap for moving to a low-carbon economy in 2050**, from http://ec.europa.eu/ clima/ policies/roadmap/ accessed on 2015-02-26

[2] **Commission proposes new rules for consumer centred clean energy transition**, from https://ec.europa.eu/energy/en/news/commission-proposes-new-rules-consumer-centred-clean-energy-transition accessed on 2019-01-05

[3] **Energetski koncept Slovenije**, from http://www.energetika-portal.si/dokumenti/strateski-razvojni-dokumenti/energetski-koncept-slovenije/ accessed on 2019-01-05

[4] **Energetska zbornica Slovenije**, from https://www.gzs.si/energetska_zbornica_slovenije/ accessed on 2019-01-05

[5] **P. Michael, K. Burgess, A. Kimball, T. Wanke**: Hydraulic Fluid Efficiency Studies in Low-Speed High-Torque Motors, SAE Technical Paper 2009-01-2848, 2009, 7, doi:10.4271/2009-01-2848

[6] **J. H. Bae, H.R. Lee, C. Kim**: Optimal Design of Gerotor with Combined Profiles (Three-Ellipse and Ellipse- Involute-Ellipse) Using Rotation and Translation Algorithm, Transactions of the Korean Society of Mechanical Engineers A, 2015, 39 (2), 169-177

[7] **X. Sang, X. Zhou, X. Liu**: Performance optimization of an oil ellipse gerotor pump for automotive engine, 5th International Conference on Advanced Design and Manufacturing Engineering (ICADME 2015), 1686-1690

[8] **G. Jacazio, A.D. Martin**: Influence of rotor profile geometry on the performance of an original low-pressure gerotor pump. Mechanism and Machine Theory, 2016, 100, 296-312

[9] **X. Dong**: Multi-Objective Optimization Design of Gerotor Orbit Motors, SAE Technical Paper 2002-01-1350, 2002, doi:10.4271/2002-01-1350

[10] **H. Ding, X.J. Lu, B. Jiang**: A CFD model for orbital gerotor motor. IOP Conference Series: Earth and Environmental Science, 2012, 15 (6)

[11] **A. Mishev, T. Stehle**: CFD-Analyse zur Leistungssteigerung eines Orbit-Motors, Untersuchung des Einflusses von Rotorzähnezahl und Exzentrizität auf die Performance des Motors, 2015

[12] **Experimental and torque identification losses in gerotor and modelling hydraulic of flow motors**, Power fluid, 1993, 0-5

[13] **J.M. Garcia**: Surface effects on start-up friction and their application to compact gerotor motor design, 2011
Available: http://search.proquest.com/docview/900865878?accountid=16468 [29.11.2016]

[14] **J. Furustig, A. Almqvist, L. Pelcastre, C.A. Bates, P. Ennemark, R. Larsson**: A strategy for wear analysis using numerical and experimental tools, applied to orbital type hydraulic motors
Available: http://pic.sagepub.com/content/early/2015/06ogled/10/0954406215590168 [29.11.2016]

[15] **G. Ranganathan, T. Hillson Samuel Raj, P.V. Mohan Ram**: Wear characterisation of small PM rotors and oil pump bearings, Tribology International, 2004, 37 (1), 1-9

[16] **Standard ISO 8426**, Hydraulic fluid power, Positive displacement pumps and motors, Determination of derived capacity, 2008

[17] **A price for business consume, Statistical Office of Slovenia**, from https://pxweb.stat.si/pxweb/Dialog/viewplus.asp?ma=H028S&ti=&path=../Database/Hitre_Repozitorij/&lang=2 accessed on 2019-01-06

Nomenclature

Symbol	Symbol meaning
n	Rotational speed
p	Pressure
Q	Flow rate
M	Torque
V	Displacement
η_T	Flow rate

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IMPROVEMENT OF A WEEDHOPPER 2 ULTRALIGHT AIRCRAFT BY USING MODERN MATERIALS

IZBOLJŠANJE ULTRALAHKEGA LETALA WEEDHOPPER 2 Z UPORABO SODOBNIH MATERIALOV

Vedran Runje, Tihomir Mihalić[ℜ], Tihana Kostadin

Keywords: ultralight aircraft, aerodynamics, composites, shell construction, glass fibre, epoxy resin, engine block carrier.

Abstract

The goal of this research was to make airworthy, to modify, and to improve the performance of a Weedhopper II ultralight aircraft (ULA) (JC-24)) manufactured in 1986. In this paper, the renovation of the existing construction and improvements with the use of modern materials and current construction techniques have been carried out. This improved the aircraft performance and removed some of the original design defects. The whole avionics system has been replaced. As the usage of composite materials has resulted in a decrease in the total mass, the determination of the new centre of gravity was carried out to ensure that the airplane remains balanced after being modified. Keeping the weight of the aircraft within the prescribed limit and ensuring that aircraft is in balance has a profound impact on flight safety. The position of the Airplane Centre Stick was changed to increase pilot ergonomics. Then, with the inspection of the engine, it was found that the replacement of the engine carrier was necessary, and the construction and production of the new carrier were performed. Furthermore, an appropriate propeller was selected, and the gearbox ratio was checked. The performances of the propeller have been measured experimentally. The construction of the trimmer of the vertical rudder was made in order to balance the aircraft. Before the flight test, aircraft balancing was performed.

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Povzetek

Cilj raziskave je spremeniti in izboljšati delovanje ultra lahkega (ULA) letala podjetja Weedhopper II, serijske številke 03786 (JC-24), izdelanega leta 1986. V članku je prikazana prenova obstoječe konstrukcije in izboljšava s sodobnimi materiali in sodobnimi gradbenimi tehnikami. Omenjene novosti so izboljšale zmogljivosti letala in zmanjšale nekatere pomanjkljivosti, ki jih je zasnova imela že od začetka. Celotna letalska elektronika je bila zamenjana. Ker je uporaba kompozitnih materialov povzročila zmanjšanje skupne mase, je bila izvedena določitev novega težišča, da se zagotovi, da bo letalo po spremembah ostalo v ravnotežju. Ohranjanje teže letala v predpisani meji in zagotavljanje, da je letalo v ravnotežju, ima velik vpliv na varen let. Položaj palice Airplane Center je bil spremenjen z namenom, da bi povečali ergonomijo pilota. S pregledom motorja je bilo ugotovljeno, da je bila potrebna zamenjava nosilca motorja, izvedena pa je bila gradnja in proizvodnja novega nosilca. Nadalje je bil izbran ustrezen propeler in preverjeno razmerje menjalnika. Izvedba propelerja je bila izmerjena eksperimentalno. Pred preskusom letenja je bilo izvedeno tudi uravnoteženje letala.

1 INTRODUCTION

In the early 1970s, the Weedhopper differed from most other UL aircraft of that period. First developed by American John Chotia in 1970, it had its first flight in 1976, causing a revolution in ultra-light aviation. According to the FAA, all aircraft that were lighter than 250 kg at take-off (aeroplane weight, baggage, fuel, and pilot) needed no permits, insurance, or maintenance to be performed by authorized companies.

***Figure 1**: Weedhopper JC-24 from 1978*

The JC-24 (Figure 1) was designed as a single-seat airplane weighing only 113 kg; it differed from other aircraft by having 2-axis manoeuvrability (transverse and vertical), rather than 3-axis (transverse, vertical, and longitudinal). The JC-24's lack of manoeuvrability in the longitudinal axis is compensated for with dihedral wings. Early versions of this aircraft had a bad reputation because of the unreliable and heavy engines available in the 1970s; that earned it the name Weedhooper. Available engines at that time were too weak and too heavy for proper flight.

2 INITIAL INSPECTION OF THE AIRCRAFT

Inspection of the aircraft and the test flight at 26°C were conducted, and the following performances were established (Table 1):

***Table 1**: Initial performances of JC-24*

Parameter	1 passenger	2 passengers
Min speed	35 km/h	40 km/h
Cruising speed	80 km/h	70 km/h
Max speed	120 km/h	120 km/h
Take off distance	40 m	60 m
Rate of climb	2 m/s	1 m/s

A flight with two passengers requires a high engine speed of around 5800-5900 rpm, resulting in high fuel consumption of some 20 l/h and significantly lower engine life. With two crew members on board, the rate of climb at the air temperature of 26°C is very poor: 1 m/s. Increasing the air temperature to 30-35 °C results in a drop in the rate of climb for 0.2-0.3 m/s, while at even higher air temperatures the aircraft could not take off. This was one of the faults of JC-24 that was to be addressed by carrying out the modifications with the usage of composites.

Visual inspection of the construction and the wing fabric revealed that the aircraft was in poor condition (Figure 2). The fabric had cracks, and stitches were loose, so it needed replacement.

***Figure 2:** Weedhopper before restoration*

The initial inspection also revealed the following: connections of aluminium components (bolts, nuts, bolts) were corroded; seats cracked with damaged seat belts; the kinematics (cables) were corroded and cracked; the motor was improperly installed, poor fuel delivery system, lack of electrical installation, etc. (Figure 3).

***Figure 3**: Weedhopper construction before restoration*

3 SELECTION OF A NEW ENGINE

Because the originally installed engine did not meet the aircraft's needs for power, it was decided to change it. Therefore, a Rotax 582 UL DCDI 99 engine was chosen, which is 11 kW (15 hp) stronger than the previous engine.

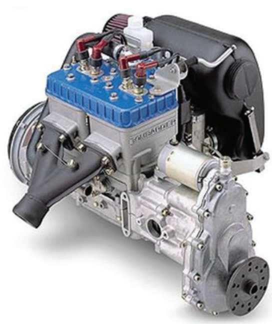

***Figure 4**: Chosen engine Rotax 582 UL DCDI 99*

Engine RPMs are given in Table 2. This factor, as well as maximum RPMs, dictates the propulsion load of the aircraft. When using propellers with an adjustable set angle, it is of great importance to properly set that angle to limit the maximum achievable engine RPMs while obtaining the maximum propeller thrust or traction force of the aircraft, *[1].*

***Table 2**: Engine RPMS at different regimes*

Parameter	RPM	Allowed time
Max allowed RPM	6800	5 min
Take off RPM	6000-6500	5 min
Cruising (75% power)	5000-5500	limitless
Take off distance	40 m	60 m
Idle	2000	3 min

4 DETERMINATION OF THE NEW CENTER OF GRAVITY

With any serious aircraft modification that requires the addition or subtraction of mass, it is necessary to determine the new aircraft's centre of gravity. This is done to ensure that the aircraft is in balance after its modifications and that has great importance for flight safety, [1].

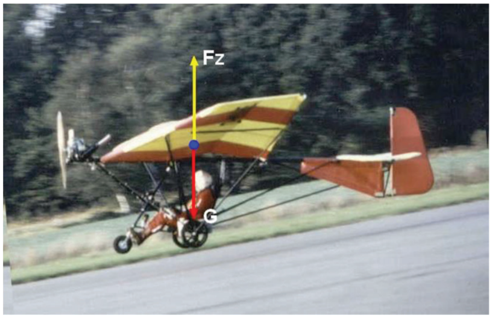

***Figure 5**: Properly balanced JC-24*

A well-balanced aircraft has a centre of gravity on the axis of a lifting force (Fz), so during a horizontal flight, the lift and weight are annulated.

The centre of gravity of this aircraft was determined empirically by suspending the aircraft with ropes on its longitudinal axis. By iterating the position of the rope, a point (using spirit levels) in which the plane is hanging perfectly horizontally was found (Figure 6).

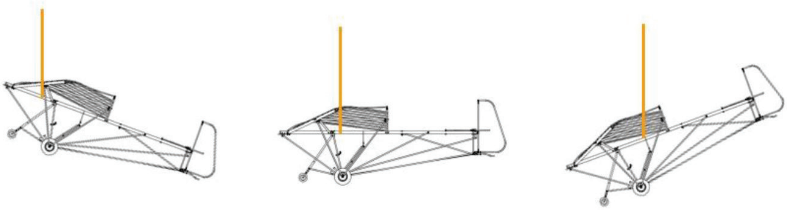

***Figure 6**: Procedure for determining the centre of gravity by rope*

It was determined that the centre of gravity is located 120 mm from the main wing's joint.

5 MODIFICATION OF THE JC-24's CENTRE STICK SYSTEM

During the initial inspection, it was found that the centre system is not suited for further use, Figure 7. The centre shoulder is practically behind the pilot, which is ergonomically awkward for users. It was decided to move the stick 100 mm forward to ergonomically meet the needs of the pilot.

***Figure 7**: Centre stick system before modification*

It was necessary to manufacture a support plate for the centre stick system, and a 3 mm thick aluminium plate (AL6061T6) was selected. The manufactured plate serves as the rear wheel brake support (Figure 8).

***Figure 8:** Modified centre stick system*

6 FEM ANALYSIS OF THE NEW ENGINE CARRIERS

A FEM analysis of the aircraft engine carrier is needed to check the stresses that occured because the stronger engine was installed, and to check whether the thrust angle had changed. Checking the angle of the thrust is necessary for the possible correction of the engine inclination, according to *[2]*. A CAD model of the ROTAX 582 with a c-gearbox (Figure 9) was created.

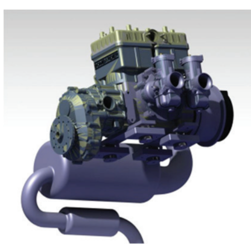

***Figure 9**: CAD model of selected engine and its gearbox*

Furthermore, a simplified FEA model was derived to shorten computational times. When simplifying (Figure 10), the model was loaded with the thrust force of 1500 N.

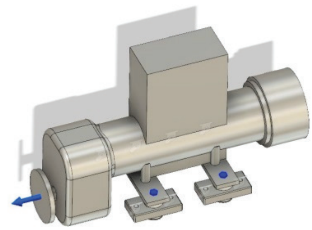

***Figure 10**: Simplified FEM model with given load and constraints*

To determine the necessary node count and finite elements sizes, displacement of the chosen model point with the coordinates (101,4; 106,9; 515,9) was calculated with different mesh properties (Figure 11).

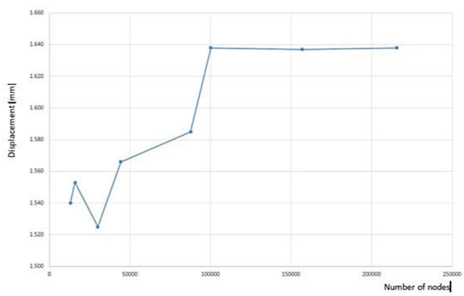

***Figure 11**: Displacement of chosen point vs. Number of nodes used for meshing*

It was concluded that the 100,000 elements were sufficient for further analysis.

The conducted FEM analysis has shown that the safety factor for designed engine carrier is in the range from 6.827 to 15, (Figure 12).

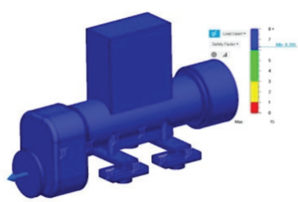

***Figure 12:** Design safety factor*

At the same time, it was shown (Figure 13) that displacement of the output crank of selected c – gearbox is 1.491 mm. According to *[3]*, a displacement of 1.491 mm does not require the engine installation angle to be changed.

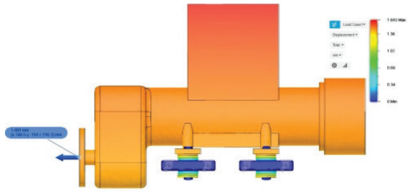

***Figure 13**: Calculated displacements by FEM*

7 MANUFACTURE OF THE NEW ENGINE CARRIERS

During an inspection of the engine carrier, it was discovered that the carriers do not meet minimum safety requirements for further exploitation. Cracks were found in the rubber section. Original carriers could not be obtained due to the year of manufacture and the small number of the aircraft produced. Therefore, it was decided to produce new engine carriers. They were designed in the CATIA CAD package (Figure 14).

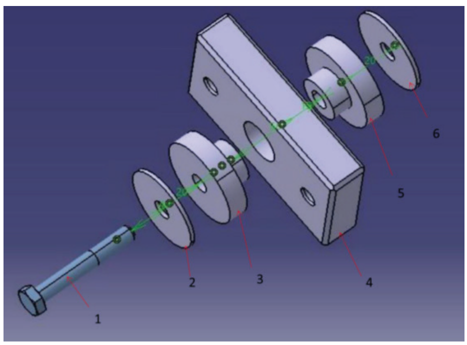

***Figure 14**: 3D model of engine carriers. 1-bolt; 2-lower washer; 3-lower part of rubber vibration reducer; 4-metal truss; 5-upper part of rubber vibration reducer; 6-upper washer*

A tool for the vulcanization of the rubber vibration reducer was designed, and the rubber 75 SH was used (Figure 15).

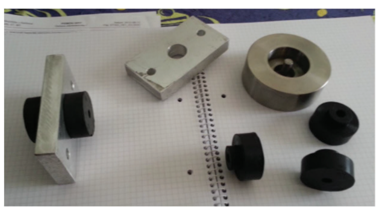

***Figure 15**: Manufactured engine carrier parts and assembly*

When installing the supporting plate connecting the aircraft carrier tube and the engine, it was moved by 20 mm forward, to balance the aircraft.

8 MEASUREMENTS OF PROPELLER PERFORMANCE

The propeller performances on our engine and our aircraft configuration were measured on the ground, *[4]*. The aircraft was tied to the dynamometer and induced traction force, depending on the engine RPM, was recorded, Figure 16.

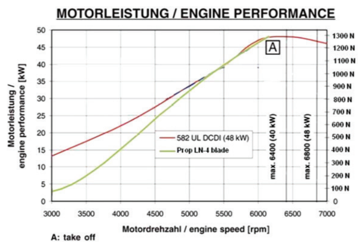

Figure 16: *Trust curve*

9 MANUFACTURE OF OPEN CABIN

The constructing of the cabin was carried out to increase aerodynamics (decrease of drag), to protect the pilot against strong air stream caused by the propeller, and to improve the aircraft's appearance, [5].

The aircraft cabin was designed as a shell whose construction was made of composite, containing knitted glass fibbers 180 g and epoxy resin PR2032. The shell is laminated in two layers of glass fibres and two coats of resin, while its fixation points to the hull of the aircraft were laminated in four layers. The windshield was made of 2 mm thick LEXAN. The total weight of the manufactured cabin is 6.2 kg (Figure17).

Figure 17: *Installed manufactured open cabin*

10 DESIGN OF THE VERTICAL RUDDER TRIMMER

The engine torque tends to rotate aircraft to the right. The value of this torque depends on the rotation of the propeller and its weight. When the rotations and the weight are bigger, the induced torque is bigger. Furthermore, additional torque occurs in relation to the number of the passengers (one or two). This torque is significant because there is a relatively big distance between the passengers.

For both reasons, the plane tends to turn right. This has to be compensated by the pilot, constantly slightly steering centre stick to the left to keep the aircraft in a straight flightpath. On longer flights, the tension of the arm leads to muscle fatigue, which is not pleasant for the pilot. Hence, the trimmer was designed to supplement the pilot's force to the left. It was designed as a spring whose tensile strength can be increased or decreased, depending on the flight regime. A 100 mm long wire spring was installed in the left lever of the vertical rudder. This spring was connected with an additional cord to the newly installed handle in the cabin for spring force adjustment, as shown in Figure 18.

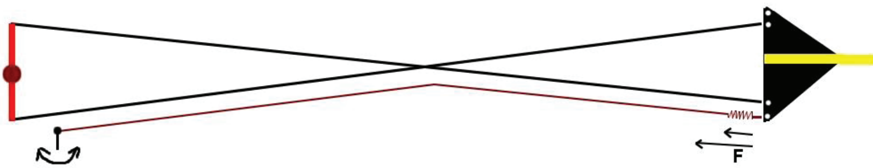

Figure 18: *Working principle of the vertical rudder trimmer*

11 MEASUREMENTS OF MODIFIED JC-24 PERFORMANCES

Figures 19 and 20 show modified JC-24 aircraft ready for test flight.

Figure 19: *Modified Weedhopper 2, right view*

Figure 20: *Modified Weedhopper 2, front view*

After a successful test flight (Figure 21), all the measurements were condensed in Table 3.

***Table 3**: JC-24 performances comparison before and after the modifications*

Parametar	Before		After		Difference (%)
Total Weight	235 kg		252.5 kg		7.4%
% of load to front wheel	14%		16%		2%
Fuel capacity	19 l		66 l		247%
Engine power	36.7 kW		47.8 kW		30%
	1passenger	2passenger	1passenger	2passenger	
Take-off speed	35 km/h	40 km/h	35 km/h	40 km/h	0%
Max speed	120 km/h	120 km/h	120 km/h	120 km/h	0%
Cruising speed	80 km/h	70 km/h	110 km/h	95 km/h	37%
Rate of climb	2 m/s	1 m/s	4.5 m/s	3 m/s	260%
Take off dis.	40 m	60 m	30 m	50 m	27%

***Figure 21**: Test flight of the renewed JC-24*

12 CONCLUSION

From this work, we can conclude that old aircraft and the other old machines can be renovated with proper analysis and the use of modern materials and current design methods. Modern materials and contemporary lighter engines even enable improving these machines and making them energy efficient. This can also be a significant benefit for the environment in the context of reusing them and preventing them to be sent to a scrapyard.

References

[1] **Weedhopper II**: Flight Manual, USA, 1982

[2] **Rotax**: Betriebhandbuch2ST, BRP-Rotax GmbH & Co KG , 1992

[3] **Rotax**: Einbauhandbuch2ST, BRP-Rotax GmbH & Co KG, 1992

[4] **Pipistrel**: Documentation for propeller LN-4, Pipistrel d.o.o., 2002

[5] **Weedhopper II**: Maintenance Manual, USA, 1982

Nomenclature

ULA	Ultralight aircraft
JC-24	Weedhopper II
FAA	Federal Aviation Administration
CAD	Computer-Aided Design
FEM	Finite Element Method
LEXAN	U.S. trademark, a polycarbonate resin

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SYSTEM CONTROL IN A CONTINUOUS STOCHASTIC INPUT PROCESS

UPRAVLJANJE SISTEMA V POGOJIH ZVEZNEGA SLUČAJNOSTNEGA VHODNEGA PROCESA

Janez Usenik[ℜ]

Keywords: continuous stochastic system, power supply system, control, energy capacities, Laplace transform

Abstract

In this article, a mathematical model of the control of a continuous stochastic production system is described. This system can also be a power supply system. An analytical model has been developed to describe the influence of production and stock on hierarchical spatial pattern and demand. In production systems where the concept of inventories/stocks does not have a standard meaning in terms of product storage, as in an energy system, they take on the role of supply of additional capacities that are optimally released according to demand. A system of differential equations describing the dynamics of a continuous system is solved using a Laplace transformation. Due to the stochastic nature of system inputs, the optimality criteria with the Wiener filter are satisfied. The Wiener-Hopf equation is solved by the spectral factorization method. The results of the presented mathematical model can be used as relevant information for the process of decision making in the operation of business systems, including energy systems. The operation of a mathematical model and the analysis of the results is illustrated with two examples of different demand functions.

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Povzetek

V članku je predstavljen matematični model upravljanja zveznega stohastičnega proizvodnega sistema. Ta sistem je lahko tudi energetski sistem. Razvit je analitični model, s katerim opišemo medsebojni vpliv proizvodnje ter zalog na hiearhično porazdeljeno prostorsko dogajanje/porabo oziroma povpraševanje. V proizvodnih sistemih, kjer pojem zalog nima standardnega pomena v smislu skladiščenja izdelkov, tak pa je tudi energetski sistem, prevzamejo vlogo zalog dodatne kapacitete, ki jih optimalno sproščamo glede na povpraševanje. Sistem diferencialnih enačb, ki opisujejo dinamiko zveznega sistema, rešimo z uporabo Laplaceove transformacije. Pogoju optimalnosti lahko zaradi stohastičnih vhodov sistema zadostimo z uporabo Wienerjevega filtra. To vodi do izpeljave Wiener-Hopfove enačbe, ki jo rešimo z metodo spektralne faktorizacije. Rezultati prikazanega matematičnega modela se lahko uporabijo kot pomembne informacije odločevalcu pri v procesu sprejemanja odločitev v delovanju poslovnih sistemov, kamor sodi tudi energetski sistem. Delovanje matematičnega modela in analiza rezultatov je ilustrirano z dvema primeroma funkcije povpraševanja.

1 INTRODUCTION

A model of optimal control is determined by a system, input variables, and the optimality criterion function. The system is represented as a regulation cycle, which generally consists of a regulator, a control process, a feedback loop, and input and output information, *[6]*, *[8]*. In this article, linear dynamic stationary continuous systems (Fig. 1) will be discussed.

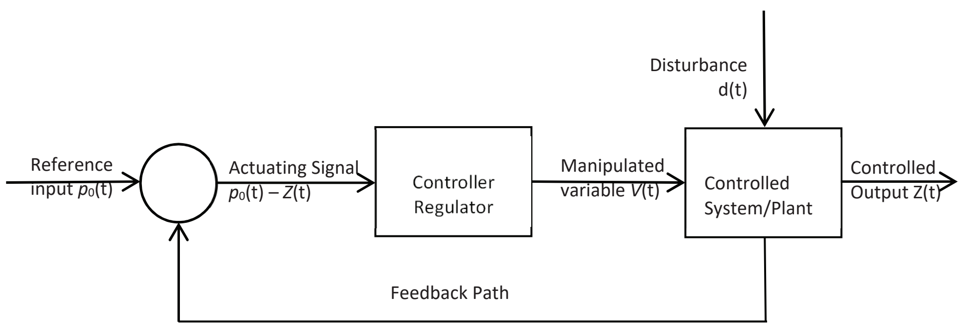

***Figure 1**: A regulation circuit*

Linear dynamic stationary stochastic continuous systems will also be discussed. The optimality criterion is optimal and synchronized, balancing planned and actual output functions.

Let us consider a production model in a linear dynamic stationary stochastic continuous system in which the input variables indicate the demand for products manufactured by a company. These variables, i.e., the demand, in this case, can either be one-dimensional or multi-dimensional vector functions, given by the conditions/restrictions matrix, or they can be deterministic, stochastic, or fuzzy, *[1]*, *[2]*. In this article, stochastic variables are presented.

Let us take a stationary random process with known mathematical expectation and autocorrelation as the demand in a stochastic situation that should be met, if possible, by current production. The difference between the current production and demand is the input function for the control process, the output function of which is the current stock. When the difference is positive, the surplus will be stocked, and when it is negative, the demand will also be covered from stock. Of course, in the case of a power supply, we do not have stock in the usual sense (such as cars or computers, etc.); energy cannot be produced in advance for a known customer nor can stock be built up for unknown customers. The demand for energy services is neither uniform in time nor known in advance. It varies, has its maxima and minima, and it can only be met by installing and activating additional proper technological capacities. Because of this, the function of maintaining stock in the energy supply process belongs to all the additional technological potential/capacities that are large enough to meet periods of extra demand, *[5]*, *[7]*, *[9].* The demand for energy services is not given and precisely known in advance. With market research, we can only learn about the probability of our specific expectations of the intensity of demand. The demand is not given with explicitly expressed mathematical function; we only know the shape and type of the family of functions. Accordingly, demand is a random process for which all the statistical indicators are known.

The output function measures the amount of unsatisfied customers or unsatisfied demand in general. When this difference is positive, i.e., when the power supply capacity exceeds the demand, a surplus of energy will be produced. When the difference is negative, i.e., when the demand surpasses the capacities, extra capacities will have to be added or, if they are not sufficient, extra purchasing from outside will have to be done. Otherwise, there will be delays, queues, etc. In the new cycle, there will be a system regulator, which will contain all the necessary data about the true state and which will, according to the given demand, provide basic information for the production process. In this way, the regulation circuit is closed (Fig. 2). With optimal control, we will achieve the situation in which all customers are satisfied with the minimum involvement of additional facilities. On the basis of the described regulation circuit, we can establish a mathematical model of power supply control.

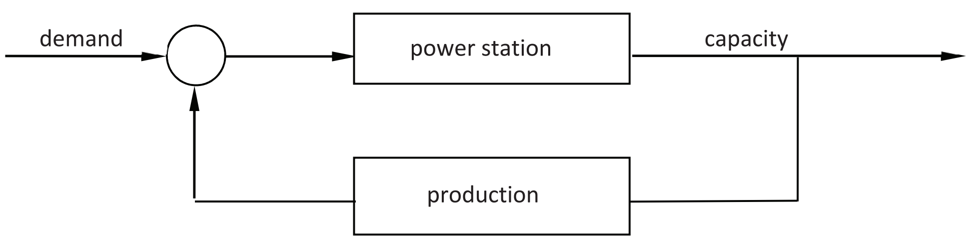

Figure 2: *Regulation circuit of the power supply system*

The task is to determine the optimum production and stock/capacities so that the total cost will be as low as possible.

In this article, the control of the continuous dynamic system using the Laplace transform is shown in the second chapter, the use of the mathematical model in the third chapter and an example with discussion, i.e., application in the fourth chapter.

2 A THEORETICAL MODEL OF THE SYSTEM CONTROL

In the building of the theoretical mathematical model, we will restrict ourselves to a dynamic linear system in which the input is a random process with known statistical properties. The system provides the output that is, due to the condition of linearity, also a random process. These processes may be continuous or discrete, *[8]*, *[9]*. In this article, we will set up the mathematical model for continuous stochastic processes.

The optimization model of dynamic system regulation is determined by the system and by the optimality criterion. The system as a regulation circuit generally consists of a regulator, the object of regulation, feedback, as well as input and output information, (Figure 1).

Due to the requirement of linearity, the connection between system quantities is simple:

$$Z(t) = L_P\left(v(t) - d(t)\right) = L_P\left(v(t)\right) - L_P\left(d(t)\right)$$
$$v(t) = L_R\left(p_0(t) - Z(t)\right) = L_R\left(p_0(t)\right) - L_R\left(Z(t)\right)$$

The operators L_P and L_R are determined by differential equations, so we use the Laplace transform, *[3]*, to solve them.

So, we have

$$Z(s) = G_p(s)\left[v(s) - d(s)\right]$$
$$v(s) = G_R(s)\left[p_0(s) - Z(s)\right]$$

With an inverse Laplace transform, the following is obtained

$$Z(t) = \int_0^t G_p(t-\tau)\left[v(\tau) - d(\tau)\right]d\tau \qquad (2.1)$$

$$v(t) = \int_0^t G_R(t-\tau)\left[p_0(\tau) - Z(\tau)\right]d\tau \qquad (2.2)$$

In practical applications, the transfer function $G_R(s)$ is written in the form

$$G_R(s) = \tilde{G}_f(s)G(s) \qquad (2.3)$$

In (2.3), $\tilde{G}_f(s)$ is an operator of fixed elements and $G(s)$ is an operator of the control. Now we have to determine $G(s)$ so that system control will be optimal.

The system can always be observed in such a way that $p_0(s) \equiv 0$. A block diagram of the system is now given on Figure 3.

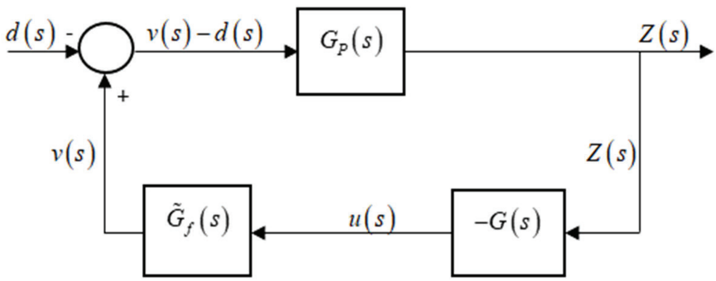

Figure 3: Block-diagram of the control system

From Fig. 3, we can see equations of the system control:

$$Z(s) = G_P(s)\left[v(s) - d(s)\right] \tag{2.4}$$

$$v(s) = \tilde{G}_f(s)u(s) \tag{2.5}$$

$$u(s) = -G(s)Z(s) \tag{2.6}$$

In real time, the space system is given from Equations (2.4)-(2.6):

$$Z(t) = \int_0^\infty G_P(\tau)\left[v(t-\tau) - d(t-\tau)\right]d\tau \tag{2.7}$$

$$v(t) = \int_0^\infty \tilde{G}_f(t)u(t-\tau)d\tau \tag{2.8}$$

$$u(t) = -\int_0^\infty G(\tau)Z(t-\tau)d\tau \tag{2.9}$$

Assuming that the input variable is a stationary random process, we can also consider the output variables to be stationary random processes because of the linearity of the system. Let us express the criterion function, the minimum of which we are attempting to define, with the mathematical expectation of the square of random variables $Z(t)$ and $u(t)$ (Wiener filter) in the form

$$Q = K_Z E\left(Z^2(t)\right) + K_u E\left(u^2(t)\right) \tag{2.10}$$

In (2.10), K_Z and K_u are positive constant factors, and have been determined empirically for the separate production system, *[8]*, *[9]*.

Let us define the functions in a complex (imaginary) plane:

$$D(s) = G_P(s)d(s) \tag{2.11}$$

$$V(s) = G_f(s)u(s) \tag{2.12}$$

$$G_f(s) = \tilde{G}_f(s)G_P(s) \tag{2.13}$$

$$W(s) = \frac{G(s)}{1 + G(s)G_f(s)} \tag{2.14}$$

Now, a flowchart may be drawn in a cascade form (Figure 4).

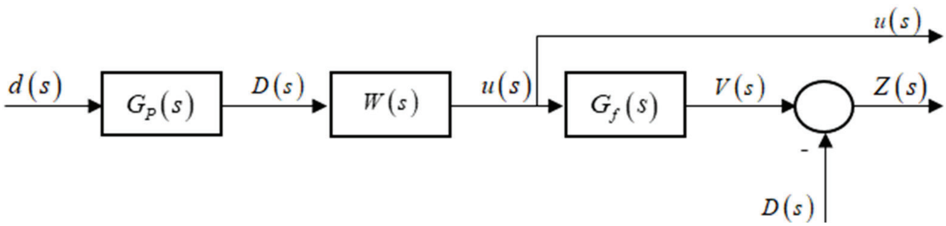

Figure 4: *The cascade flow-chart*

In accordance with the definition of the autocorrelation is valid $E\left(Z^2(t)\right) = R_{ZZ}(0)$ and $E\left(u^2(t)\right) = R_{uu}(0)$ and the criterion function (2.10), the minimum of which we are trying to determine, is in the following form $Q = K_Z R_{ZZ}(0) + K_u R_{uu}(0)$ or divided by $K_Z > 0$

$$P = R_{ZZ}(0) + A^2 R_{uu}(0) \tag{2.15}$$

where $P = \dfrac{Q}{K_Z}$ and $A^2 = \dfrac{K_u}{K_Z}$.

From Figure 4, it can be seen that $u(s) = W(s)D(s)$ and $Z(s) = \left[W(s)G_f(s) - 1\right]D(s)$. Spectral densities from $R_{ZZ}(t)$ and $R_{uu}(t)$ are as follows:

$$\Phi_{ZZ}(s) = L\left\{R_{ZZ}(t)\right\} = \int_0^\infty R_{ZZ}(t)e^{-st}dt = \left[W(s)G_f(s) - 1\right]\cdot\left[W(-s)G_f(-s) - 1\right]\Phi_{DD}(s) \tag{2.16}$$

$$\Phi_{uu}(s) = L\{R_{uu}(t)\} = \int_0^{\infty} R_{uu}(t) e^{-st} dt = W(s)W(-s)\Phi_{DD}(s) \tag{2.17}$$

Both Equations (2.16) and (2.17) are transformed in the real-time space and inserted into Equation (2.15):

$$\begin{aligned} P = R_{ZZ}(0) + A^2 R_{uu}(0) = R_{DD}(0) - 2\int_{-\infty}^{\infty} W(t_1) dt_1 \int_{-\infty}^{\infty} G_f(t_2) R_{DD}(t_1+t_2) dt_2 + \\ + \int_{-\infty}^{\infty} W(t_1) dt_1 \int_{-\infty}^{\infty} G_f(t_2) dt_2 \int_{-\infty}^{\infty} W(t_3) dt_3 \int_{-\infty}^{\infty} G_f(t_4) R_{DD}(t_1+t_2-t_3-t_4) dt_4 + \\ + A^2 \int_{-\infty}^{\infty} W(t_1) dt_1 \int_{-\infty}^{\infty} W(t_2) R_{DD}(t_1-t_2) dt_2 \end{aligned} \tag{2.18}$$

We are looking for the minimum of Equation (2.07). This minimum is obtained with the variation calculus [4]:

$$W(t) = W_{opt}(t) + \eta W_{\eta}(t) \tag{2.19}$$

In (2.19), the function $W_{\eta}(t)$ is a variation of the function $W(t)$, η represents a variation parameter and $W_{opt}(t)$ is the optimal solution of (2.14).
Insert (2.19) into Equation (2.18):

$$\begin{aligned} P = R_{DD}(0) - 2\int_{-\infty}^{\infty} \left[W_{opt}(t_1) + \eta W(t_1)\right] dt_1 \int_{-\infty}^{\infty} G_f(t_2) R_{DD}(t_1+t_2) dt_2 + \\ + \int_{-\infty}^{\infty} \left[W_{opt}(t_1) + \eta W(t_1)\right] dt_1 \int_{-\infty}^{\infty} G_f(t_2) dt_2 \int_{-\infty}^{\infty} \left[W_{opt}(t_3) + \eta W(t_3)\right] dt_3 * \\ * \int_{-\infty}^{\infty} G_f(t_4) R_{DD}(t_1+t_2-t_3-t_4) dt_4 + A^2 \int_{-\infty}^{\infty} \left[W_{opt}(t_1) + \eta W(t_1)\right] dt_1 * \\ * \int_{-\infty}^{\infty} \left[W_{opt}(t_2) + \eta W(t_2)\right] R_{DD}(t_1-t_2) dt_2 \end{aligned}$$

From the requirement $\left.\frac{dP}{d\eta}\right|_{\eta=0} = 0$ we obtain function $W(t)$. From (2.18) and (2.19), the Wiener-Hopf equation is derived, *[6] - [9]*:

$$\begin{aligned} \int_{-\infty}^{\infty} W_{opt}(t_3) dt_3 \left[\int_{-\infty}^{\infty} G_f(t_2) dt_2 \int_{-\infty}^{\infty} G_f(t_4) R_{DD}(t_1+t_2-t_3-t_4) dt_4 + A^2 R_{DD}(t_1-t_3)\right] - \\ - \int_{-\infty}^{\infty} G_f(t_2) R_{DD}(t_1+t_2) dt_2 = 0 \quad for \quad t_1 \geq 0 \end{aligned} \tag{2.20}$$

The second variation

$$\frac{d^2P(\eta)}{d\eta^2} = \int_{-\infty}^{\infty} W_\eta(t_1)dt_1 \int_{-\infty}^{\infty} F_f(t_2)dt_2 \int_{-\infty}^{\infty} W_\eta(t_3)dt_3 \int_{-\infty}^{\infty} G_f(t_4)R_{DD}(t_1+t_2-t_3-t_4)dt_4 + \\ + A^2 \int_{-\infty}^{\infty} W_\eta(t_1)dt_1 \int_{-\infty}^{\infty} W_\eta(t_2)R_{DD}(t_1-t_2)dt_2$$

is positive for every $t_1 \geq 0$ and the solution $W_{opt}(t)$ of Equation (2.09) is the minimum.

The Wiener-Hopf Equation (2.20) is solved by the spectral factorisation method, *[4].*

If we define functions

$$\Psi(t_1) = \int_{-\infty}^{\infty} G_f(t_2)R_{DD}(t_1+t_2)dt_2 \tag{2.21}$$

and

$$\Theta(t_1-t_3) = \int_{-\infty}^{\infty} G_f(t_2)\int_{-\infty}^{\infty} G_f(t_4)R_{DD}(t_1+t_2-t_3-t_4)dt_4 + A^2R_{DD}(t_1-t_3) \tag{2.22}$$

the Wiener-Hopf Equation (2.20) is obtained in the following form:

$$\int_{-\infty}^{\infty} W_{opt}(\tau)\Theta(t-\tau)d\tau - \Psi(t) = 0 \qquad for \ \ t \geq 0 \tag{2.23}$$

Using the Wiener spectral factorisation method and define

$$\Theta(t) = \int_{-\infty}^{\infty} \Theta^-(t_2)\Theta^+(t-t_2)dt_2 \tag{2.24}$$

where

$$\Theta^+(t) = \begin{cases} 0 & for\ t<0 \\ \Theta(t) & for\ t \geq 0 \end{cases} \qquad \Theta^-(t) = \begin{cases} 0 & for\ t>0 \\ \Theta(t) & for\ t \leq 0 \end{cases} \tag{2.25}$$

In a similar way

$$\Psi(t) = \int_{-\infty}^{\infty} \Theta^-(t)\pi(t-t_2)dt_2 \tag{2.26}$$

With these auxiliary functions, Equation (2.23) can be written in the form

$$\int_{-\infty}^{\infty} W_{opt}(\tau)\Theta^+(t_1-\tau)d\tau - \pi(t_1) = 0 \tag{2.27}$$

Now we have to ensure the validity of Equation (2.27) for all *t*, so we read

$$\pi(t_1) = \pi^+(t_1) + \pi^-(t_1)$$
$$\pi^+(t_1) = 0 \quad for\ t_1 < 0 \qquad (2.28)$$
$$\pi^-(t_1) = 0 \quad for\ t_1 > 0$$

From (2.27) the Wiener-Hopf equation is now obtained in the following form:

$$\int_0^\infty W_{opt}(\tau)\Theta^+(t-\tau)d\tau - \pi^+(t) = 0 \ \text{ for } \ every\ t \in (-\infty,\infty) \qquad (2.29)$$

This equation is an ordinary integral equation of the first order, which can be solved by the Laplace transform:

$$W_{opt}(s)\Theta^+(s) - \pi^+(s) = 0$$

and finally

$$W_{opt}(s) = \frac{\pi^+(s)}{\Theta^+(s)} \qquad (2.30)$$

Using the Laplace transform on Equation (2.24):

$$\Theta(s) = \Theta^-(s)\Theta^+(s) \qquad (2.31)$$

The function $\Theta^+(s)$ has its zeros (i.e. poles of (2.30)) only on the left side of the complex plane (s_1, s_2, s_3 in Figure 5). Similarly, the function $\Theta^-(s)$ has its zeros on the right side of the complex plane (s_4, s_5, s_6 in Figure 5).

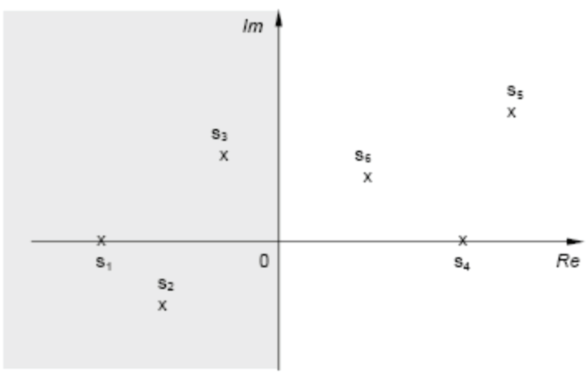

Figure 5: Poles of the function (2.23)

$$\Psi(s)=\Theta^{-}(s)\pi(s) \tag{2.32}$$

$$\pi(s)=\pi^{+}(s)+\pi^{-}(s)$$

Furthermore, the function $\pi^{+}(s)$ has its poles only in the left half-complex plane, whereas $\pi^{-}(s)$ only in the right half-complex plane.

From (2.32), we have

$$\pi^{+}(s)=\left(\frac{\Psi(s)}{\Theta^{-}(s)}\right)^{+}$$

Let us make the Laplace transform on Equations (2.21) and (2.22):

$$\Psi(s)=G_f(-s)\Phi_{DD}(s)=G_f(-s)\Phi_{DD}^{+}(s)\Phi_{DD}^{-}(s)$$

$$\Theta(s)=G_f(s)G_f(-s)\Phi_{DD}(s)+A^2\Theta_{DD}(s)$$

The optimal solution for the cascade operator is obtained in formal design by (2.30). The functions in Equation (2.30) are defined with expressions in the Laplace form:

$$\pi^{+}(s)=\left(\frac{G_f(-s)\Phi_{DD}^{+}(s)}{\left(G_f(s)G_f(-s)+A^2\right)^{-}}\right)^{+}$$

$$\Theta^{+}(s)=\left(G_f(s)G_f(-s)+A^2\right)^{+}\Phi_{DD}^{+}(s)$$

3 DEFINING THE PROBLEM FOR THE POWER SUPPLY CONTROL

Let us consider a production model in a linear dynamic stationary stochastic continuous system in which the input variables indicate the demand for products manufactured by a company.

Beginning with a stationary random process X, with the known mathematical expectation, $E(X)$ and autocorrelation $R_{XX}(t)$, as the demand in a stochastic situation that should be met, if possible, by the current production. The difference between the current production and demand is the input function for the control process; the output function is the current stock. In the case of a power supply, stock in the usual sense does not exist, because energy cannot be produced in advance. The demand for energy services is neither uniform in time nor known in advance. It varies, has its ups (maxima) and downs (minima), and it can only be met by installing and activating additional proper technological capacities. Because of this, the function of stock in the energy supply process is held by all the additional technological potential/capacities, large enough to meet periods of extra demand. The demand for energy services is not given and precisely known in advance. With market research, we can only learn about the probability of our specific expectations of the intensity of demand. Demand is a random process for which all the statistical indicators are known.

The system input represents the demand for the products/services that a given subject offers. Let demand be a stationary random process with two known statistical characteristics: mathematical expectation and autocorrelation function. Any given demand should be met with current production. The difference between the current capacity of production/services and demand is the input function for the object of control. The output function measures the amount of unsatisfied customers or unsatisfied demand in general. When this difference is positive, i.e., when the power supply capacity exceeds the demand, a surplus of energy will be made. When the difference is negative, i.e., when the demand surpasses the capacities, extra capacities will have to be added or, if they are not sufficient, extra external purchasing will have to be done. Otherwise, there will be delays, queues etc. In the new cycle, there will be a system regulator, which will contain all the necessary data about the true state and that will, according to given demand, provide basic information for the production process. In this way, the regulation circuit is closed (Fig. 2). With optimal control, we will achieve the situation in which all customers are satisfied with the minimum involvement of additional facilities. On the basis of the described regulation circuit, we can establish a mathematical model of power supply control, a system of differential equations for continuous systems *[9]*, in our situation. A mathematical model of control for this system will be structured around the theoretical model of control of linear stationary systems. For this model, the regulation circuit is given in Figure 2.

The task is to determine the optimum production and capacities (stock) so that the total cost will be as low as possible.

Notations for $t \geq 0$ are as follows:

$Z(t)$ - additional capacities at a given time *t*,

$u(t)$ - production at time *t*,

$d(t)$ - demand for product at time *t*,

λ - lead time

Let $Z(t)$, $u(t)$ and $d(t)$ be stationary continuous stationary random variables/functions.
Now the system will be modelled with the equations:

$$\dot{Z}(t)=\psi\left[v(t)-d(t)\right],\ \psi\in R^{+} \tag{3.1}$$

$$v(t)=u(t-\lambda) \tag{3.2}$$

$$u(t)=-\int_{0}^{t}G(\tau)Z(t-\tau)d\tau \tag{3.3}$$

In Equation (3.3), the function $G(t)$ is the weight of the regulation that must be determined at optimum control so that the criterion of the minimum total cost is satisfied. The parameter λ, called the "lead time", is the period needed to activate the additional capacities in the power supply process. We used a real situation in which any goods can be sold to the customer only from the "storehouse of finished goods", because only in this case can the information flow of a company be updated and in accordance with legislation. Assuming that the input variable demand is a stationary random process, we can also consider production and additional capacities to be stationary random processes for reasons of the linearity of the system.

Let us express the total cost, the minimum of which we are attempting to define, with the mathematical expectation of the square of random variables $Z(t)$ and $u(t)$:

$$Q(t)=K_Z E\left(Z^2(t)\right)+K_u E\left(u^2(t)\right) \tag{3.4}$$

or

$$P(t)=E\left(z^2(t)\right)+A^2 E\left(u^2(t)\right), \ A^2=\frac{K_u}{K_z} \tag{3.5}$$

In (3.4), K_Z and K_u are positive constant factors, attributing greater or smaller weight to individual costs. Both factors have been determined empirically for the product and are therefore in the separate plant, *[1]*.

Equations (3.1)-(3.5) represent a linear model of control in which we have to determine the minimum of the mean square error if by means of a parallel shift we cause the ideal quantity to equal zero.

Functions of the system are normally transferred into the complex area by means of the Laplace transform. Let be functions $Z(s),\ D(s),\ u(s),\ v(s)$ Laplace transforms of the real functions $Z(t),\ d(t),\ u(t),\ v(t)$.

When the Laplace transform is now performed on the functions of the system (3.1)-(3.3), we obtain the expressions:

$$Z(s)=\frac{1}{s}\left[v(s)-d(s)\right] \tag{3.6}$$

$$v(s)=e^{-\lambda s}u(s) \tag{3.7}$$

$$u(s)=-G(s)Z(s) \tag{3.8}$$

Comparing the equations of the general system, the expressions are defined, as follows

$$G_P(s)=\frac{1}{s} \tag{3.9}$$

$$\tilde{G}_f(s)=e^{-\lambda s} \tag{3.10}$$

$$D(s) = \frac{1}{s} \cdot d(s) \tag{3.11}$$

$$G_f(s) = \frac{e^{-\lambda s}}{s} \tag{3.12}$$

$$V(s) = \frac{e^{-\lambda s}}{s} \cdot u(s) \tag{3.13}$$

$$W(s) = \frac{G(s)}{1 + G(s) G_f(s)} \tag{3.14}$$

$$u(s) = W(s) D(s) \tag{3.15}$$

$$Z(s) = \left[W(s) G_f(s) - 1 \right] D(s) \tag{3.16}$$

$$W_{\text{opt}}(s) = \frac{\left(\frac{G_f(-s) \Phi_{DD}^{+}(s)}{\left(G_f(s) G_f(-s) + A^2 \right)^{-}} \right)^{+}}{\left(G_f(s) G_f(-s) + A^2 \right)^{+} \Phi_{DD}^{+}(s)} \tag{3.17}$$

4 AN EXAMPLE

For the problem (3.1)-(3.4), let the autocorrelation function of demand be in the form

$$R_{dd}(\tau) = \sigma^2 e^{-\alpha|\tau|} \quad , \sigma > 0 \tag{4.1}$$

The spectral density of the given autocorrelation function is as follows:

$$\Phi_{dd}(s) = \mathscr{L}\left\{ R_{dd}(t) \right\} = \frac{2\alpha\sigma^2}{\alpha^2 - s^2} \tag{4.2}$$

From $D(s) = G_p(s) d(s) = \frac{d(s)}{s}$ we obtain

$$\Phi_{DD}(s) = -\frac{2\alpha\sigma^2}{s^2 \left(s^2 - \alpha^2 \right)}$$

and in the right half-plane

$$\Phi_{DD}^{+}(s) = \frac{1}{s(s+\alpha)}$$

Due to

$$\left[G_f(s)G_f(-s)+A^2\right]^- = A-\frac{1}{s} \quad \text{and} \quad \left[G_f(s)G_f(-s)+A^2\right]^+ = A+\frac{1}{s}$$

we can obtain

$$\pi^+(s)=\left(\frac{G_f(-s)\Phi_{DD}^+(s)}{\left(G_f(s)G_f(-s)+A^2\right)^-}\right)^+=\left(\frac{e^{\lambda s}}{s(s+\alpha)(1-As)}\right)^+=\frac{1}{\alpha s}-\frac{e^{-\alpha\lambda}}{\alpha(s+\alpha)(1+A\alpha)}$$

$$\Theta^+(s)=\left(G_f(s)G_f(-s)+A^2\right)^+\Phi_{DD}^+(s)=\left(A+\frac{1}{s}\right)\cdot\frac{1}{s(s+\alpha)}$$

And the optimal cascade operator

$$W_{opt}(s)=\frac{\pi^+(s)}{\Theta^+(s)}=\frac{s(Ms+1)}{As+1} \tag{4.3}$$

where

$$M=\frac{1+A\alpha-e^{-\alpha\lambda}}{\alpha(1+A\alpha)} \tag{4.4}$$

Now we can obtain the operator of the optimum regulation

$$G(s)=\frac{W_{opt}(s)}{1-W_{opt}(s)G_f(s)}=\frac{s(Ms+1)}{(As+1)-e^{-\lambda s}(Ms+1)}$$

in order to obtain:

a) the optimal production:

$$u_{opt}(s)=W_{opt}(s)G_p(s)d(s)=\frac{Ms+1}{(As+1)}\cdot d(s) \tag{4.5}$$

b) the optimal stock/additional capacities:

$$Z_{opt}(s)=G_f(s)u_{opt}(s)-D(s)=\left[\frac{Ms+1}{As+1}e^{-\lambda s}-1\right]\cdot D(s) \tag{4.6}$$

c) delayed services:

$$V_{opt}(s)=G_f(s)u_{opt}(s)=\frac{Ms+1}{As+1}\cdot e^{-\lambda s}D(s)$$

With the inverse Laplace transform, we obtain these functions in the time area:

a) $u_{opt}(t)=\frac{1}{A}\left[Md(t)+\frac{A-M}{A^2}\int_0^t e^{-\frac{\tau}{A}}d(t-\tau)d\tau\right]$ (4.8)

b) $Z_{opt}(t)=\left(\frac{M}{A}\cdot D(t-\lambda)+\frac{A-M}{A^2}\int_0^t e^{-\frac{(t-\lambda)}{A}}D(t-\tau-\lambda)d\tau\right)-D(t)$ (4.9)

c) $V_{opt}(t)=\left(\frac{M}{A}\cdot D(t-\lambda)+\frac{A-M}{A^2}\int_0^t e^{-\frac{(t-\lambda)}{A}}D(t-\tau-\lambda)d\tau\right)$ (4.10)

4.1 Discussion

In these data and results, parameters λ, α and A have influence on the values of functions and on the results of control. These parameters are involved in the constant M.

According to parameter λ, the interesting option is $\lambda=0$. This means there are no delays in the production system. In this case, they would be optimal values

$$G_{opt}(s)=\frac{Ms+1}{s(A-M)}$$

$$Z_{opt}(s)=\left(\frac{Ms+1}{As+1}-1\right)D(s)=\left(\frac{Ms+1}{As+1}-1\right)\cdot\frac{d(s)}{s}$$

Because of $u_{opt}(s)=-G_{opt}(s)Z_{opt}(s)$ and (5.5) is in this case

$$\frac{Ms+1}{(As+1)}\cdot d(s)=\frac{Ms+1}{s(A-M)}\cdot\left(\frac{Ms+1}{As+1}-1\right)\cdot\frac{d(s)}{s}$$

If $Ms+1\neq 0$ then this equation has only one solution $s=1$, and if $Ms+1=0$, then the left and the right side are identical. This means that our problem degenerates into an idealized situation that has no real meaning. In other words: the mathematical model has a real meaning only if it takes into account the real possibility of delay, i.e. $\lambda>0$.

According to parameters α and A, the discussion is sensible by analysis of factor $\frac{A-M}{A^2}$, which multiplies all the convolution integrals (4.8)-(4.10). There are three possibilities: $A-M=0$, $A-M<0$ and $A-M>0$.

a) $A-M=0$

In this case, $A = M$ and because of $\alpha > 0$, $\lambda > 0$ and $1 - e^{-\alpha\lambda} = B \in (0,1)$ is obtained $\alpha = \frac{\sqrt{B}}{A}$.

Therefore the optimal solutions

$$u_{opt}(t) = d(t)$$

$$V_{opt}(t) = D(t-\lambda)$$

$$Z_{opt}(t) = D(t-\lambda) - D(t) = V_{opt}(t) - D(t)$$

are completely idealized and do not meet the real requirements.

b) $A - M < 0$

In this case, the optimum production and optimal capacity (stock) would be negative, which means they could not meet demand. Such degeneration occurs in case $\alpha < \frac{\sqrt{B}}{A}$. Due to $A = \sqrt{\frac{K_u}{K_Z}}$, is from $\alpha < \frac{\sqrt{B}}{A}$: $K_Z > \frac{\alpha^2}{B} \cdot K_u$. In the case ($K_Z > K_u$), the storing and activating of extra capacities is very expensive, and we have to cover the demand with the present capacities, i.e., the present production of services.

c) $A - M > 0$

In this case, demand is evenly distributed between the use of standard and additional capacity. Such a situation represents a rational organization of the production system. Now $\alpha > \frac{\sqrt{B}}{A}$ or $K_Z < \frac{\alpha^2}{B} \cdot K_u$, which means that the cost of activating additional capacity is lower than the cost of current production with average capacities, so extreme situations in demand (peaks) can be realized with minor additional costs. That means the production of services depends on the demand in a given moment more than from previous demand. For that reason, we will cover the demand with extra capacities.

5 CONCLUSION

In this article, the model of the control of the power supply system has been presented; the input functions (and for reason of linearity and stationarity, also an output function) were given as continuous stochastic processes. On the basis of the specific items of the systems, the mathematical model of a system for the possibility of input/output functions being random processes was created and solved.

A theoretical mathematical model of system control can also be used in an energy technology system and (if necessary) in all their subsystems. Input-output signals are continuous functions.

For operations, many conditions have to be fulfilled. During the control process, a great deal of information must be processed, which can only be done if a transparent and properly developed information system is available. The solution, i.e., optimal control functions, depends on many numerical parameters. For the study of the structure, interrelationships, and operation of a phenomenon with system characteristics, the best method is the general systems theory, and (within it) the systems regulation theory. When we refer to system technology as a synthesis of organization, information technology, and operations, we have to consider its dynamic dimension when creating a mathematical model. As such a complex phenomenon makes up a system, the technology in this article is again dealt with as a dynamic system. Elements of the technological system compose an ordered entity of interrelationships and thus allow the system to perform production functions. Because of the condition of linearity, the response functions of the system are continuous. During the operation of the power station, a large amount of data is produced, which can only be processed into information for control if high quality software and powerful hardware are available. However, we must know that theoretically optimal solutions always are for decision makers only additional information to help them to decide, *[10].* Each decision-maker has to determine how this information will be used.

References

[1] **M. Bogataj, J. Usenik**: Fuzzy approach to the spatial games in the total market area. *International journal of production economics*, Vol. 93–94, pp. 493–503, 2005

[2] **D. Kovačič, J. Usenik, M. Bogataj**: Optimal decisions on investments in urban energy cogeneration plants - extended MRP and fuzzy approach to the stochastic systems. *International journal of production economics*, Vol. 183, part B, pp. 583-595, 2017

[3] **E. Kreyszig**: *Advanced Engineering Mathematics*, John Wiley & Sons, Inc., New York, 1999

[4] **C. Schneeweiss**: *Regelungstechnische stochastische Optimierung Verfahren in Unternehmensforschung und Wirtschsaftstheorie*, Springer Verlag, Berlin, 1971

[5] **J. Usenik, M. Bogataj**: A fuzzy set approach for a location-inventory model. *Transportation planning technology*, Vol. 28, no. 6, pp. 447–464, 2005

[6] **J. Usenik, M. Vidiček, M. Vidiček, J. Usenik**: Control of the logistics system using Laplace transforms and fuzzy logic. *Logistics and sustainable transport*, Vol. 1, issue 1, pp. 1-19, 2008

[7] **J. Usenik**: Mathematical model of the power supply system control. *Journal of Energy Technology*, Vol. 2, iss. 3, pp. 29-46, 2009

[8] **J. Usenik, M. Repnik**: System control in conditions of discrete stochastic input process. *Journal of energy technology*, Vol. 5, iss. 1, pp. 37-53, 2012

[9] **J. Usenik:** Differential equations, difference equations and fuzzy logic in control of dynamic systems. *Journal of energy technology*, Vol. 9, iss. 2, pp. 39-54, 2016

[10] **Winston, W., L.:** *Operations research, Applications and Algorithms*, Duxbury Press, Belmont, California, pp. 771-804, 1994

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RESEARCH ACTIVITIES OF THE LABORATORY FOR ENERGY MANAGEMENT AND ENGINEERING

RAZISKOVALNE AKTIVNOSTI LABORATORIJA ZA ENERGETSKI MENEDŽMENT IN INŽENIRING

Zdravko Praunseis[ℜ]

Keywords: laboratory, research activities, energy management, energy engineering, energy efficiency of buildings, biomass.

Abstract

This paper aims to present the main research activities of the Laboratory for Energy Management and Engineering, which can be roughly divided into energy management, energy engineering, and consulting and testing of biomass as energy-generating products. The main missions of the Laboratory for Energy Management and Engineering are basic and applied research and the transfer of knowledge to society and industry. The laboratory is also focused on scientific research in the fields of environmental protection, and monitoring the environmental processes in connection with new and clean forms of energy. Finally, in the article research activities of the Laboratory for Energy Management and Engineering are described in detail.

Povzetek

Namen članka je predstaviti glavne raziskovalne aktivnosti Laboratorija za Energetski menadžment in inženiring, ki jih lahko v grobem razdelimo na energetski menadžment, energetski inženiring, energetsko učinkovitost stavb in biomaso. Glavno poslanstvo Laboratorija za Energetski menadžment in inženiring je izvajanje temeljnih in aplikativnih raziskav in prenos znanja v družbeno okolje

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in industrijo. Laboratorij je v okviru znanstvenih raziskav fokusiran tudi na področje varstva okolja in spremljanje okoljskih procesov v povezavah z novimi in čistimi energijami. V članku so podrobno predstavljene in opisane raziskovalne dejavnosti Laboratorija za Energetski menadžment in inženiring.

1 ENERGY ENGINEERING

The research activities of the Laboratory for Energy Management and Engineering regarding energy engineering are the following:

– Developing pressure vessels, pipelines and reservoirs with a particular accent on safe operation and making project documentation,

– Making of welding draft and processes for demanding applications (pipelines, pressure vessels, nuclear technology),

– Monitoring of quality and execution of supervision for demanding welding applications,

– Making of safety plans for making pressure vessels, pipelines and reservoirs,

– Problems of engines with internal and external combustion and their solvability with the diagnostic system,

– Fracture mechanics of energy components (lifetime assessment of elements, etc.).

The Laboratory for Energy Management and Engineering is qualified for mechanical and technological testing of metallic as well as non-metallic materials and welded joints according to valid SIST, EN, DIN, and ISO standards. Activities also include the evaluation, expert validation and research of metallic materials and joined parts. The basic mechanical testing includes tensile test and compression test at room temperature, according to the SIST EN ISO 6892-1 standard and Vickers microhardness measurement, according to the SIST EN ISO 6507-1 standard and three-point and four-point bending testing of materials up to the load of 100 kN. Fracture mechanics tests are performed by fracture Single edge notch bend (SENB) and Crack Tension (CT) specimens to determine the proper fracture toughness of basic materials and welded joints (Figure 1 and Figure 3).

Figure 1: *Universal Testing machine Zwick Roel, 100KN, testing of all kinds of materials*

Mechanical testing can also be accompanied by chemical and metallographic investigations (Figure 2, Figure 4 and Figure 5).

Figure 2*: Automatic grinding & polishing machine*

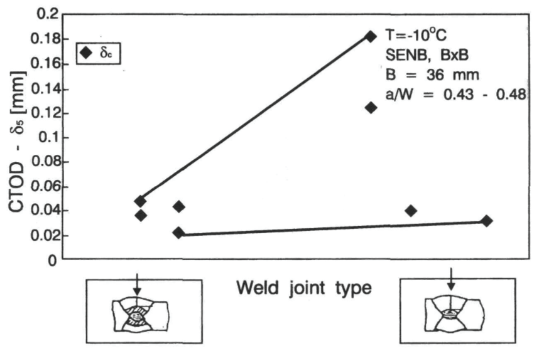

Figure 3: *Soft root layer CTOD fracture toughness of heterogeneous undermatched weld joints, [1].*

In this case, metallographical investigations (Figure 5) comprise micro- and macroscopic investigations of metals and alloys, qualitative and quantitative microstructural analyses, identification (definition and interpretation) of the micromorphology of fractures and surfaces, and macro- and microstructural examinations using optical microscopes (Figure 4).

Figure 4: *Zeiss stereomicroscope*

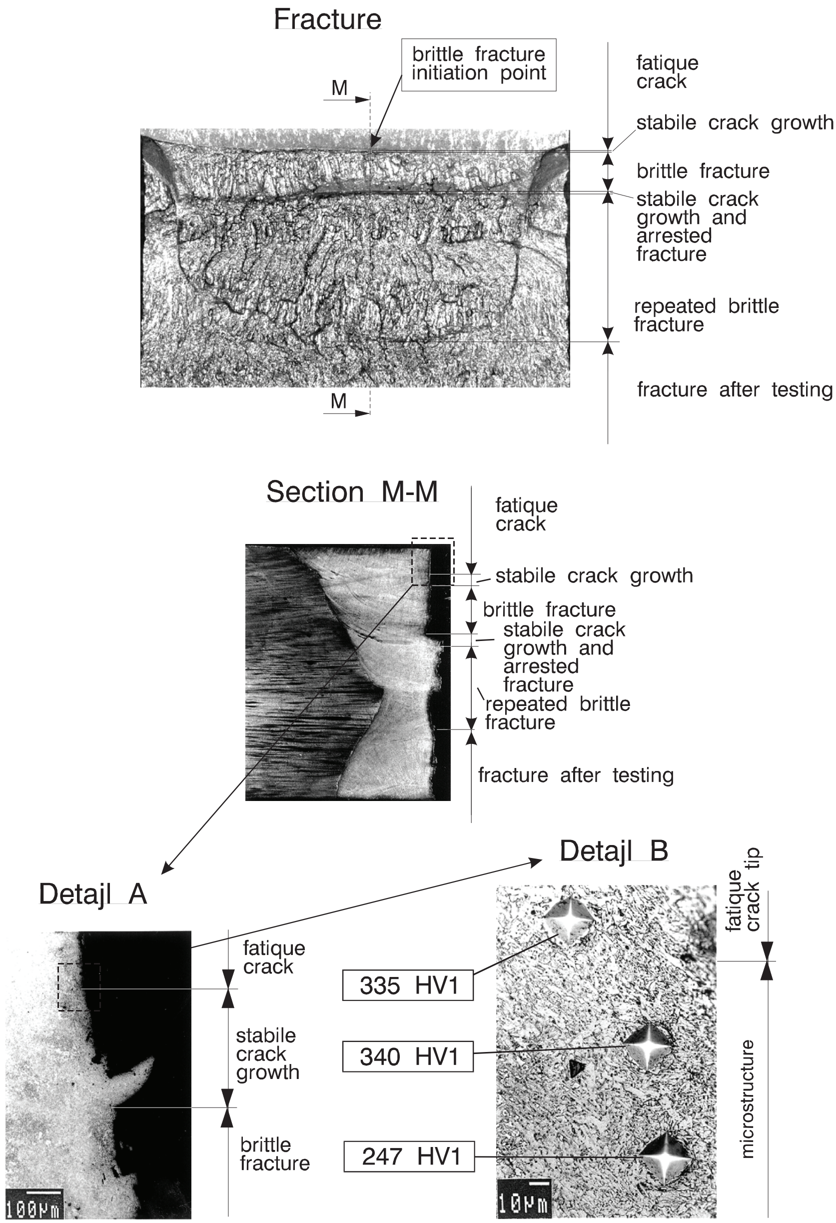

Figure 5: *Fracture and microstructure in the vicinity of brittle fracture initiation point of specimen B × B with surface crack (a/ W = 0.25) in the filler region of the homogeneous weld. At the vicinity of brittle fracture initiation point a bainitic microstructure (Detail ~ A) is visible, and at higher magnification (Detail - B) contours of primary ferrite (PF) can be seen, formed at primary γ grains [2].*

Chemical analyses are performed with X-ray fluorescence spectrometry (XRF) using an XRF X-ray fluorescence spectrometer (Thermo Scientific Niton XL3t GOLDD+). Nondestructive testing (NDT) is the process of inspecting, testing, or evaluating materials, components or assemblies for discontinuities, or differences in characteristics without destroying the serviceability of the part or system. In other words, when the inspection or test is completed the part can still be used. NDT is used to ensure the quality of materials and joining processes during the fabrication and erection phases, and in-service NDT inspections are used to ensure that the products in use continue to have the integrity necessary to ensure their usefulness and the safety of the public. The laboratory used for NDT testing the Penetrant Testing method(PT), Magnetic Particle Testing method (MT) and Ultrasonic Testing method (UT). The basic principle of liquid penetrant testing is that when a very low viscosity (highly fluid) liquid (the penetrant) is applied to the surface of a part, it will penetrate fissures and voids open to the surface. Once the excess penetrant is removed, the penetrant trapped in those voids will flow back out, creating an indication.

Magnetic Particle Testing uses one or more magnetic fields to locate surface and near-surface discontinuities in ferromagnetic materials. The magnetic field can be applied with a permanent magnet or an electromagnet. When using an electromagnet, the field is present only when the current is being applied. When the magnetic field encounters a discontinuity transverse to the direction of the magnetic field, the flux lines produce a magnetic flux leakage field of their own. Because magnetic flux lines do not travel well in air, when very fine coloured ferromagnetic particles ("magnetic particles") are applied to the surface of the part the particles will be drawn into the discontinuity, reducing the air gap and producing a visible indication on the surface of the part. The magnetic particles may be a dry powder or suspended in a liquid solution, and they may be coloured with a visible dye or a fluorescent dye that fluoresces under ultraviolet ("black") light.

Ultrasonic testing uses the same principle as used in naval sonar and fish finders. Ultra-high frequency sound is introduced into the part being inspected and if the sound hits a material with a different acoustic impedance (density and acoustic velocity), some of the sound will be reflected back the sending unit and can be presented on a visual display. By knowing the speed of the sound through the part (the acoustic velocity) and the time required for the sound to return to the sending unit, the distance to the reflector (the indication with the different acoustic impedance) can be determined.

One of research directions of the laboratory regarding welding is the basic research of welding methods (Figure 6), especially MIG/MAG, as well as the development of welding procedures and weldability, *[1,2,4].*

Figure 6: *Welding of high strength steels, robotic welding*

Chemical, power, and process engineering plants are often exposed to heat, aggressive media, and high pressure. This requires special corrosion- and acid-resistant steel that is mechanically resilient even at high temperatures. If the ferrite content in such steel is too low, the weldment is susceptible to hot-cracking, if the ferrite content is too high, the toughness and ductility, as well as the corrosion resistance of the steel, are reduced. In duplex steel, a lack of ferrite causes a reduction in stress corrosion cracking and strength in the weld area; thus, delta ferrite measuring is necessary.

2 ENERGY MANAGEMENT

Research activities of the Laboratory for Energy Management and Engineering in the field of energy management are the following:

- Monitoring of systems, measuring of energy consumption and making reports for energy consumption in buildings,
- Developing expertise and proposals with measures for better energy-efficiency and management,
- Making of a central monitoring system for energy system with optimization,
- Managing and running of energy projects (energy project management).

"Energy management" is a term that has a number of meanings, but the Laboratory for Energy Management and Engineering is more concerned with those related to saving energy in homes than in businesses [3,5,6].

Regarding energy saving, energy management is the process of monitoring, controlling, and conserving energy in a building or organization. Typically this involves the following steps:

- Metering energy consumption and collecting the data.
- Finding opportunities to save energy, and estimating how much energy each opportunity could save. One would typically analyze meter data to find and quantify routine energy waste, and possibly also investigate the energy savings that could be made by replacing equipment (e.g., lighting) or by upgrading a building's insulation.
- Taking action to target the opportunities to save energy (i.e., tackling the routine waste and replacing or upgrading the inefficient equipment). Typically one would start with the best opportunities first.
- Tracking progress by analysing meter data to see how well energy-saving efforts have worked.

While energy management has been popular in larger buildings for a long time; it has only recently started catching on in homes. Most homeowners are not even aware of the term and take more of a haphazard, flying-blind approach to reducing their energy consumption.

However, the monitoring and results-driven approach used by professional energy managers is just as effective in the home as it is in larger buildings.

The modern approach to energy data collection is to fit interval metering systems that automatically measure and record energy consumption at short, regular intervals, such as every 15 minutes or half hour. Detailed interval energy consumption data makes it possible to see patterns of energy waste that would be impossible to see otherwise.

3 ENERGY EFFICIENCY OF BUILDINGS

Research activities of the Laboratory for Energy Management and Engineering in the field of Energy efficiency of buildings are the following:

– Consultancy for energy reconstruction of all kind of buildings (according to EU directives EPBD and local regulations),
– Making and preparing of elaborates and rough outlines of energy solution for making of project documentation (PGD), permission for building for zero and low energy buildings,
– Making documentation of the process, fire and explosive safety,
– Developing and using modern materials for energy components and plants,
– Thermography for all types of building,
– Preparing and issuing of energy certificates for all types of building,
– Energy audits of buildings,
– Designing microgenerators of heat on the basis of RES (biomass, geothermal energy) for passive and low-energy buildings (Stirling),

- Designing micro energy systems for the needs of zero energy buildings,
- Dimensioning of district heating for residential buildings.

Buildings are responsible for at least 40% of energy use in most countries. The absolute figure is rising fast, as construction is booming, especially in countries such as China and India. It is essential to act now because buildings can make a major contribution to tackling climate change and energy use, *[7].*

Progress can begin immediately because knowledge and technology exist today to slash the energy that buildings use while simultaneously improving levels of comfort. Behavioural, organisational, and financial barriers stand in the way of immediate action, and three approaches can help overcome them:

- Encouraging interdependence by adopting holistic, integrated approaches among the stakeholders that assure a shared responsibility and accountability toward improved energy performance in buildings and their communities
- Making energy more valued by those involved in the development, operation and use of buildings
- Transforming behaviour by educating and motivating the professionals involved in building transactions to alter their course toward improved energy efficiency in buildings.

Energy performance certificates provide information for consumers on buildings they plan to purchase or rent. They include an energy performance rating and recommendations for cost-effective improvements.

Certificates must be included in all advertisements in commercial media when a building is put up for sale or rent. They must also be shown to prospective tenants or buyers when a building is being constructed, sold, or rented. After a deal has been concluded, they are handed over to the buyer or new tenant.

EU countries must also put in place schemes for the inspection of heating and air-conditioning systems, or take measures that have an equivalent impact on energy savings.

Under the Energy Performance of Buildings Directive (EPGD), all EU countries have established independent control systems for energy performance certificates and inspection reports for heating and cooling systems.

Infrared (IR) thermography (Figure 7) is a nondestructive investigative tool used in numerous applications within buildings for preventative maintenance, energy conservation, quality control, and security functions.

Figure 7: *IR camera, temperature ranges up to +1200 °C*

It is also used for quality control purposes in the commissioning of architectural, structural electrical, and mechanical systems in new buildings and major retrofits and evaluations of architectural, structural, electrical, and mechanical systems for building condition reports on existing buildings. With an IR camera, inspections of exterior walls of buildings can be made to identify air leaks, insulation defects, voids within materials, moisture accumulation, as well as potential mould and fungi formation leading to indoor air quality problems. Roof inspections detect roof leaks though water accumulation within insulation layers.

4 BIOMASS

The research activities of the Laboratory for Energy Management and Engineering in the field of biomass are the following:

– Consulting about biomass as energy-generating products
– Introducing and testing new energy agriculture products
– Developing innovations for all types of burners and stoves
– Testing of all types of burners (Figure 8)
– Testing and monitoring of biomass quality (pellets, wood-chips, straw)
– Developing expertise and analysis for the heating process in buildings (burning, chimney, fume analyses)
– Co-generation-Trigeneration with biomass combination and the making of technical documentation with the calculation for district heating.

Figure 8: *Material research for burners (pellets, wood-chips, straw),*

Biomass is a term for all organic material that stems from plants (including algae, trees and crops). Biomass is produced by green plants converting sunlight into plant material through photosynthesis and includes all land- and water-based vegetation, as well as all organic wastes. The biomass resource can be considered as organic matter, in which the energy of sunlight is stored in chemical bonds. When the bonds between adjacent carbon, hydrogen, and oxygen molecules are broken by digestion, combustion, or decomposition, these substances release their stored, chemical energy. Biomass has always been a major source of energy for mankind and is presently estimated to contribute 10–14% of the world's energy supply.

The energy provided may be heat, electricity, or mechanical power. The biological material may come from animal or plant sources (including animal wastes and composts), whilst the transformative process may be direct combustion or perhaps involve gasification, fermentation, or pyrolysis. The status of biomass as a renewable, low carbon fuel means there is growing interest in using it to help meet local and national targets for renewable energy. As a relatively mature renewable energy technology, biomass can be one of the most cost-effective and therefore attractive technologies to use.

Cogeneration or combined heat and power (CHP) is the simultaneous generation of useful thermal energy and mechanical or electrical energy from a single fuel source. Because CHP recovers heat that would otherwise be wasted, for example from certain industrial processes, it makes much more efficient use of the primary energy. CHP can use this waste heat to produce electricity or for industrial processes, district heating and cooling systems (DHC) for residential and commercial buildings. Cogeneration can also help make better use of renewable energy technologies based on biomass, concentrating solar power and geothermal energy, by using them to produce both heat and electricity, for example, to power an absorption refrigerator to provide cooling in summer, giving tri-generation, *[7].*

Many people believe that since wood smoke is a natural substance, it is not harmful. However, smoke from wood stoves and fireplaces is a major part of the EU's air pollution problem.

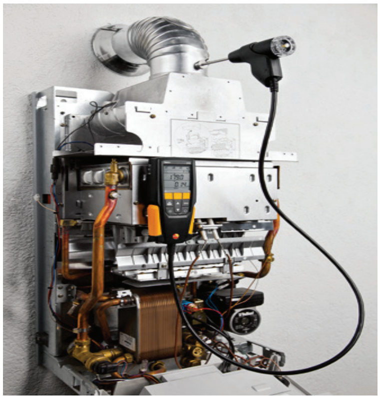

Figure 9: *Flue gas analyser*

Wood smoke contains tiny particles and gases that can have serious health effects when inhaled. When people use wood stoves and fireplaces, chemicals are released into the air. Some of these chemicals are poisonous, some irritate the respiratory tract, and some may cause cancer. Wood smoke is more of a problem in the winter when cold, stagnant air prevents it from rising and dispersing. As wood burning increases during these cold periods, the pollutants in the smoke are trapped near the ground; thus, the measurement of chimney smoke hard particles is necessary (Figure 9 and Figure 10).

Figure 10: *Fine particle analyser of smoke gases*

5 CONCLUSIONS

The Laboratory for Energy Management and Engineering is qualified for the mechanical and technological testing of metallic as well as non-metallic materials and welded joints according to valid SIST, EN, DIN, and ISO standards. Activities also include the evaluation, expert validation, and research of metallic materials and joined parts.

Energy management has been popular in larger buildings for a long time; it has only recently become common for homes. Most homeowners are not even aware of the term and take more of a haphazard, flying-blind approach to reducing their energy consumption. However, the monitoring and results-driven approach used by professional energy managers is just as effective in the home as it is in larger buildings.

Energy performance certificates provide information for consumers on buildings they plan to purchase or rent. They include an energy performance rating and recommendations for cost-effective improvements. Certificates must be included in all advertisements in commercial media when a building is put up for sale or rent. They must also be shown to prospective tenants or buyers when a building is being constructed, sold, or rented. After a deal has been concluded, they are handed over to the buyer or new tenant.

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References

[1] Z**. Praunseis:** *The influence of soft root layer on fracture toughness of HSLA weldments, Doctoral dissertation, University of Maribor, 1998*

[2] Z. **Praunseis:** *Fracture evaluation of energy components with local brittle zones = Vrednotenje loma v energetskih komponentah z lokalnimi krhkimi področji. Journal of energy technology, Vol. 6, Iss. 1, p.p. 51-60, 2013*

[3] **Z. Praunseis, R. Strojko:** *Energy renovation of an older house. Science journal of energy engineering, Vol. 2, Iss. 4, p.p. 47-52, 2014*

[4] **Z. Praunseis, M. Toyoda:** *The transferability of fracture-mechanics parameters to fracture performance evaluation of welds with mismatching. Materiali in tehnologije,Vol. 7, Iss. 1, p.p. 34-41, 2000*

[5] **S. Novak, B. Krajnc, J. Avsec, Z. Praunseis:** *Vpliv energetskih strategij na izvajanje projektov OVE in URE v lokalnih skupnostih. V: Konovšek, Damjan (ur.). EnRe : energy & responsibility : zbornik referatov, 3. mednarodna konferenca Energetika in klimatske spremembe, Velenje, p.p. 1-7, 2013*

[6] **Z. Praunseis, T. Naglič:** *Incubators as entities of innovative environment and generation of high-tech enterprises for realisation of these innovative business ideas = Inkubatori kao entiteti inovativnog okruženja i generacije visoko-tehnoloških preduzeća za realizaciju inovativnih poslovnih ideja. V: RISTOVIĆ, Ivica (ur.), VULIĆ, Milivoj (ur.). Energetsko rudarstvo, nove tehnologije, održivi razvoj = Energy Mining, New Technologies, Sustainable Development : zbornik radova = proceedings, III međunarodni simpozijum Energetsko rudarstvo 2010, 08-11. Septembar, 2010, Apatin = 3rd International Symposium Energy Mining 2010, 08-11 September, 2010, Apatin, Serbia. Beograd: Rudarsko-geolološki fakultet Univerziteta, 2010, p.p. 393-397, Beograd*

[7] **Z. Praunseis, R. Strojko:** *Energetska oskrba objektov. [1. izd.]. Krško: Fakulteta za energetiko, p.p. 1-286, Univerzitetni učbenik, Krško, 2014*

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Main text should be structured logically in chapters, sections and sub-sections. Type of letters is Calibri, 10pt, full justified.

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[1] Organisation, Department, Address

[2] Organisation, Department, Address

Units and abbreviations: Required are SI units. Abbreviations must be given in text when first mentioned.

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Chapter examples:

1 MAIN CHAPTER

(Arial bold, 12pt, after paragraph 6pt space)

1.1 Section

(Arial bold, 11pt, after paragraph 6pt space)

1.1.1 Sub-section

(Arial bold, 10pt, after paragraph 6pt space)

Example of Equation (lined 2 cm from left margin, equation number in normal brackets (section. equation number), lined right margin, paragraph space 6pt before in after line):

Equation (1.1)

Tables should have a legend that includes the title of the table at the top of the table. Each table should be cited in the text.

Table legend example:

Table 1: *Name of the table (centred, on top of the table)*

Figures and images should be labelled sequentially numbered (Arabic numbers) and cited in the text – Fig.1 or Figure 1. The legend should be below the image, picture, photo or drawing.

Figure legend example:

Figure 1: *Name of the figure (centred, on bottom of figure, photo, or drawing)*

References

[1] **N. Surname:** *Title,* Journal Title, Vol., Iss., p.p., Year of Publication

[2] **N. Surname:** *Title,* Publisher, Year of Publication

[3] **N. Surname:** *Title* [online], Publisher or Journal Title, Vol., Iss., p.p., Year of Publication. Available: website (date accessed)

Examples:

[1] **J. Usenik**: *Mathematical model of the power supply system control*, Journal of Energy Technology, Vol. 2, Iss. 3, p.p. 29 – 46, 2009

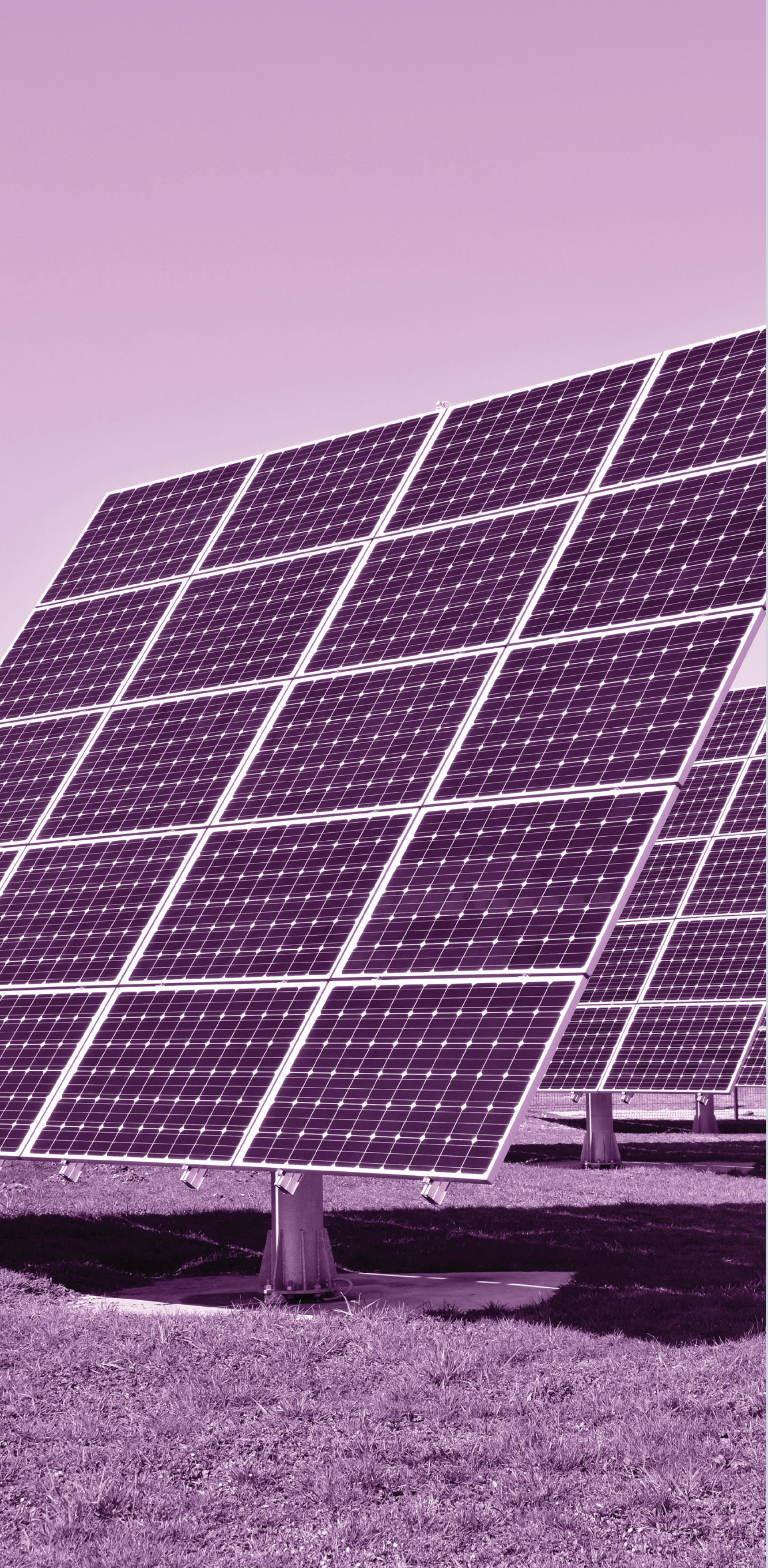
[2] **J. J. DiStefano, A.R. Stubberud, I. J. Williams**: *Theory and Problems of Feedback and Control Systems*, McGraw-Hill Book Company, 1987

[3] **T. Žagar, L. Kegel:** *Preparation of National programme for SF and RW management taking into account the possible future evolution of ERDO* [online], Journal of Energy Technology, Vol. 9, Iss. 1, p.p. 39 – 50, 2016. Available: http://www.fe.um.si/images/jet /Volume 9_Issue1/03-JET_marec_2016-PREPARATION_OF_NATIONAL.pdf (7. 10. 2016)

Example of reference-1 citation: In text *[1],* text continue.

Nomenclature

(Symbols)	(Symbol meaning)
t	time



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