Bulgarian Academy of Sciences. Space Research and Technology Institute.
Aerospace Research in Bulgaria. 34, 2022, Sofia

DOI: https://doi.org/10.3897/arb.v34.e10

SYSTEMS FOR SECONDARY ELECTRIC POWER SUPPLY OF THE INSTRUMENTS "ZORA" AND "NEUROLAB-B" — SPACE MEDICINE

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Keywords: *Secondary power supply system, Space medicine instrumentation, "Mir" Space Station, International Space Station*

Abstract

The "Zora" and "Neurolab-B" instruments solved problems related to the study, control and prediction of astronaut health. The "Zora" instrument is a computer system for collecting and processing data from complex neurophysiological experiments: "Statokinetiks", "Labyrinth", "Potential"; "Leisure Time"; "Questionary", etc. The system for complex research of the psychophysiological state of astronauts "Neurolab-B" is used for scientific experiments with the help of a number of international crews. Engineering solutions are proposed according to the investigated specificity of the powered devices. Both systems have been operating on board the Mir space station — "Neurolab-B" from 1996 to 2000. New space medicine instruments used on the Russian sector of the international space station are considered. Since 2000, four new secondary power systems for space instruments have been developed at the Institute of Space Research and Technology — Bulgarian Academy of Sciences. They are applicable in both space physics and space medicine.

1. Secondary power supply systems of the instrument "Zora"

The requirements of the Mir Space Station (Mir SS) for the secondary power supply system (SPS) of the "Zora" instrument, Fig. 1a, are as follows [1, 2, 3]:

- The service life shall be a minimum of 5 years.
- The average time to failure of the equipment shall be 300 h.
- Full operability at Ta = +5 to +35°C.
- The "Zora" instrument must operate under voltage ripple generated by the on-board network (BN) with parameters according to Tab. 1.
- The level of electromagnetic noise generated by the scientific instrumentation (SI) of the BN shall not exceed the levels shown in Fig. 2a and Fig. 2b.

The "Zora" structure, Fig. 1a, consists of four modules:

• Aluminum housing;
• Laptop “GRiD Compass”, or microprocessor system (MPS1).
• SPS cartridge.
• Digital and analogue circuit boards.

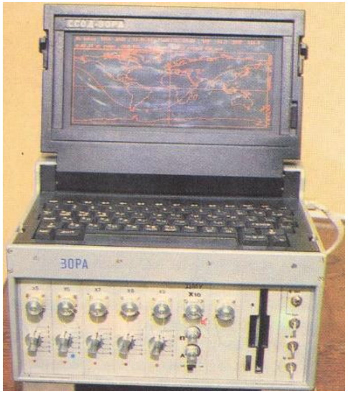

Fig. 1a. “Zora” instrument
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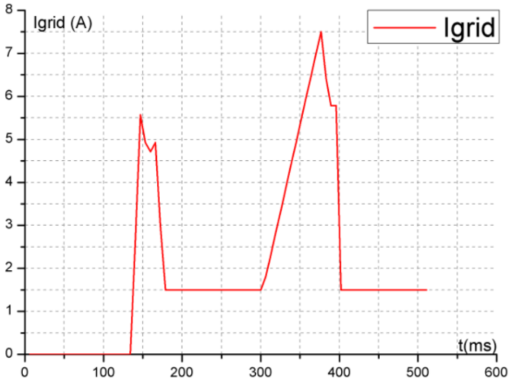

Fig. 1b. MPS1 start process in circuit +16 Vgrid

Table 1. Sinusoidal ripple current and voltage generated by the BN at the Mir SS, [1]

Current frequency	Current sensor voltage, RMS
10÷25 [Hz]	0,25 [V]
25÷60 [Hz]	0,25÷0,1 [V]
60÷250 [Hz]	0,1 [V]
250÷1700 [Hz]	0,1÷0,15 [V]
1700÷6500 [Hz]	0,15 [V]
6,5÷150 [KHz]	150÷0,5 [mV]
0,15÷1[MHz]	500÷100 [μV]
1÷100[MHz]	100 [μV]
Voltage frequency	Voltage [V], RMS
10÷25 [Hz]	0,8 [V]
25÷60 [Hz]	0,8÷0,3 [V]
60÷250 [Hz]	0,3 [V]
250÷1700 [Hz]	0,3 [V]÷1 [V]
1700÷2000 [Hz]	1 [V]
20÷150 [KHz]	1÷0,15 [V]
0,15 ÷ 1 [MHz]	0,15÷0,003 [V]

Structurally, the instrument SPS, Fig. 3a, consists of five circuit boards: the PSA; PSW; PSD and PSC and an automatic start-up circuit (ASS). Two identical

PSA and PSW sources (each 24 W) power the most important consumer (MPS1) and have the following characteristics:

- Using the "hot" and "cold" reserve mode of the MPS1.
- Two-stage auto start and dynamic current limiting.
- Automatic shutdown when the voltage of the BN is exceeded or reduced;
- Suppression of current ripple and inrush current of MPS1 in BN.

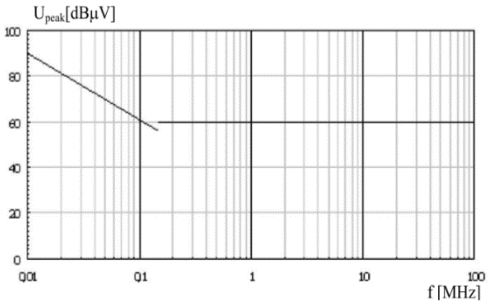

Fig. 2a. Radio frequency levels noises created by SI in BN of the Mir SS [1]

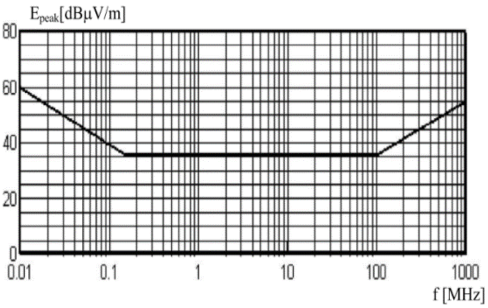

Fig. 2b. Electric field strength of radio noises, created by the SI in the Mir SS [1]

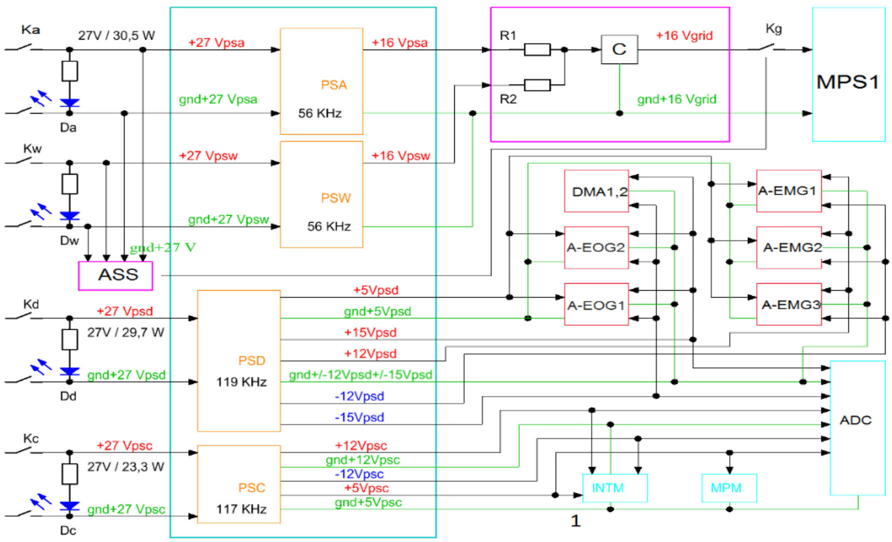

Fig. 3a. Functional diagram of the SPS of the instrument "Zora"

When the Ka switch is turned on, the Da indicator for PSA lights up. For a time of 0,5 s to 1 s, the safety circuit automatically turns off the PSA if: the +16 Vpsa voltage is higher than a set upper level, lower than a set lower level, or a short circuit has occurred in its outputs. A circuit solution has been chosen to sum the voltages +16 Vpsa and +16 Vpsw to a single voltage +16 Vgnd across the R-C filter board. A voltage of +16 Vgrid across contact Kg of the polarized relay from ASS is supplied to power MPS1. When both switches (Ka and Kw) are on, PSA and PSW operate in "hot" reserve mode. For some of the planned experiments, operation of PSA, PSW and MPS1 alone is sufficient. As needed in different experiments, the Kc and Kd switches power the PSC module most often and the PSD module less often. In this way, the resources of the power supply and the "Zora" elements are saved. The results for the starting current of MPS1 at Vgrid = 16 V are shown in Fig. 1b. According to these measurements, unacceptable currents will be obtained in the BN, so an R-C circuit (R1, R2 and C) has been added.

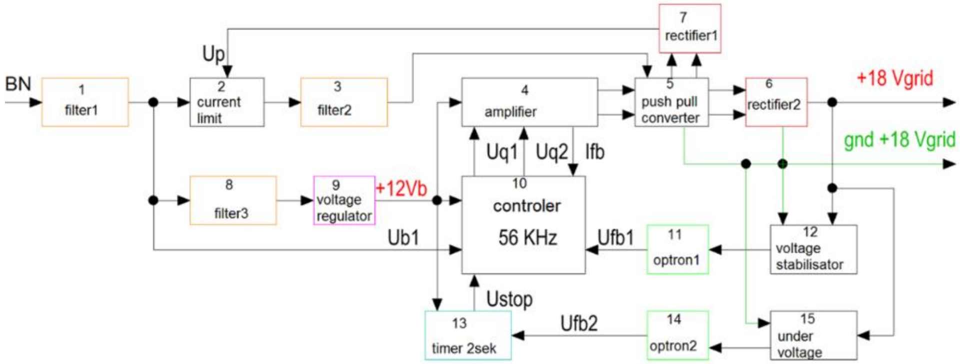

Fig. 3b. Functional diagram of PSA and PSW of the instrument "Zora"

Conventionally, at time zero a command is given to turn on Kg, but the relay closes at time T = 130 ms when the charging process of part of the capacitors in MPS1 starts and the pulse converter for the digital part built into MPS1 is started. At the moment T = 300 ms, the second start-up process in MPS1 (high voltage converter for the display) starts and continues until T = 400 ms. Once the voltage is applied to BN 4, 9, 10 and 13 are powered, see Fig. 3b. The voltage at Ub1 is used for negative feedback of the board voltage and for undervoltage estimation of BN. When Ub1 exceeds 14 V, operation of 10 is enabled and the PSA start-up process is enabled. When the +18 Vgrid output voltage exceeds the value of 13 V during normal startup within 2 *s*, 10 and 14 generate the Uvb2 signal, which stops the operation of 13 and disables the Ustop signal, at which the PSA operates normally. In an emergency, when the +18 Vgrid voltage drops below 13 V for a time greater than 100 ms, Uvb2 drops out and the Ustop signal disables the PSA from operating continuously. This condition is maintained until the Ka switch is opened. To reduce the EMC emissions radiated by the PSA and PSW, the two collectors of the power key transistors and their common heatsink are galvanically connected to the BN plus bus.

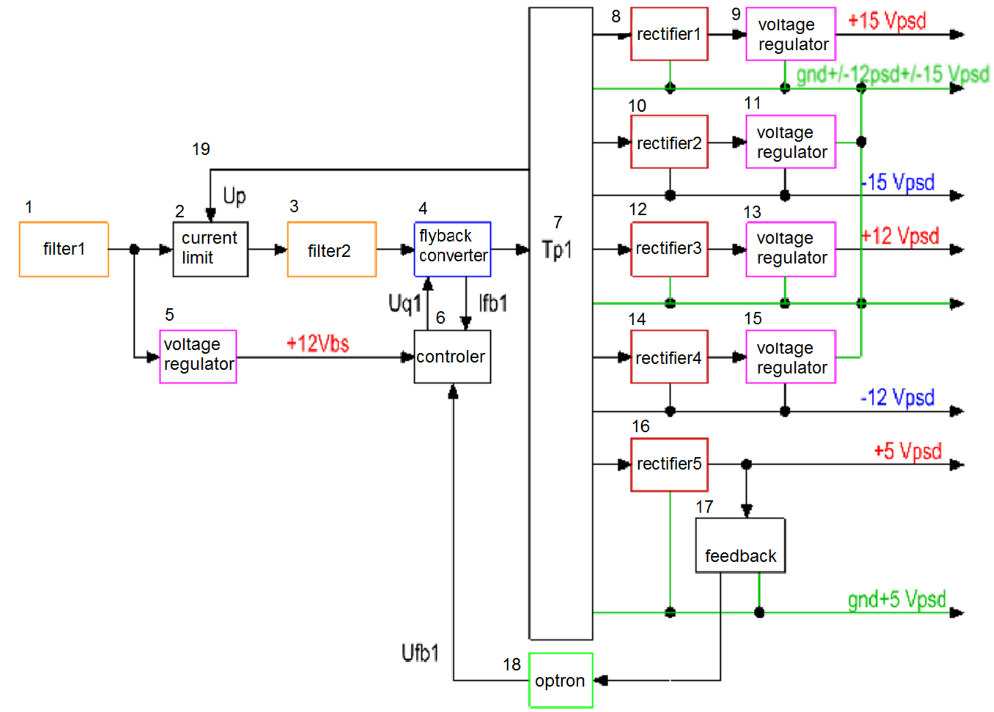

Fig. 4a. Functional diagram of the secondary power supply PSD of the instrument "Zora"

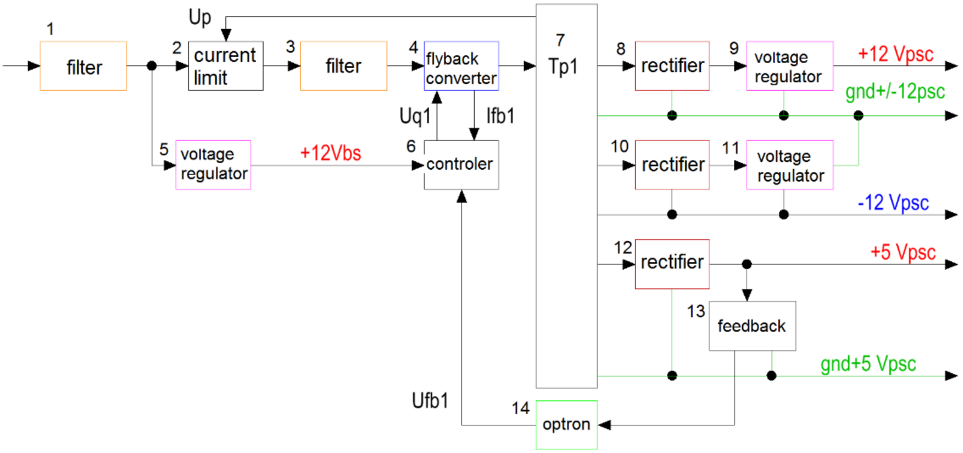

Fig. 4b. Functional diagram of the PSC of the instrument "Zora"

Fig. 4a shows the functional diagram of the PSD. The PSD is designed to power the digital telemetry, MPS2 and ADC (INTM, MPM and ADC respectively).

The functional diagram of the PSC is shown in Fig. 4b. The PSC is designed to power analog ICs in the boards for: electromyography; electrooculography; dynamometry (EMG, EOG and DMA) and ADC. The same principle and mounting scheme are used for the PSC and PSD, but the PSC does not mount the +/-15 Vpsd elements. From "Zora" were made 5 pieces: trainer, LK-1, LK-2, LK-3 and LK-4, one of the flying specimens was used for a long time on board of the Mir SS [4, 5, 8].

2. Secondary power supply systems of instrument "Neurolab-B"

Fig. 6 shows the functional diagram of "Neurolab-B" instrument, where the average power dissipated by individual users is given. The Neurolab-B (fig. 5a and 5b) system consists of three main power consumers:

- Digital part (2, 3, 4, 5, 6, 7, 8), fed by SPS-D: (1, 9).
- Analogue part (11, 12, 13, 14, 16, 17, 18, 19, 20) fed by SPS-A: (10, 15). The main consumption for 10 is from the operational amplifiers (11 and 12).
- Laptop 22 powered by SPS-20: (21).

Fig. 5a. Neurolab-B instrument https://rait-aerospace.com/photogalery/_016.jpg

Fig. 5b. SPS for the Neurolab-B instrument https://rait-aerospace.com/photogalery/_018.jpg

Prior to the 21 design, the following power supply parameters were measured (under different 22 modes at +20 V):

- 11,4 W with display off.
- 17 W when the display is on. The current ripple is 280 Hz and has an amplitude of +/-18 % with respect to the average value of 0,85 A;
- 19 W with display and hard drive included. Current ripple amplitude is +/-18.4% of the mean value of 0.95 A at 280 Hz.

Under these conditions, the performance of the SPS-20V was measured at four BN voltage values: 22 V, 24 V, 27 V, and 34 V. For these voltages the following efficiency values were measured for the SPS-20V: 73 %, 73.5 %, 74.5 % and 76 %.

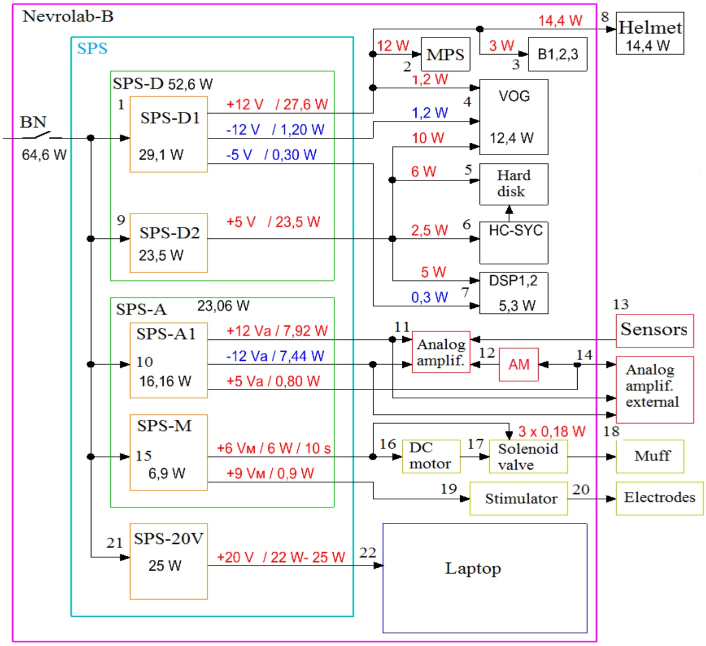

Fig. 6. Functional diagram of the SPS of the instrument "Neurolab-B"

The SPS-M provides +6 Vm to power the DC motor of the blood pressure pump and +9 Vm to power the stimulator for high-voltage pulses that are applied to the human body via electrodes. This motor runs for a maximum of 10 s and makes a minimum pause of 60 s. The air pressure created by it is passed by three electromagnetic pneumatic valves (17) to the cuff (18) of the astronaut's arm.

The rotor resistance is 5.5 Ω, the power at start-up is 6,54 W, and at idle it consumes 1,38 W. The average power while maintaining the maximum cuff pressure is 2,4 W. Then the motor current ripple measured in the supply lines has a frequency of 480 Hz and its power varies 1,5÷2,58 W. An L-C filter is used to minimize the current ripple. It has a frequency of 94 Hz, with capacitor and inductance values of 2,2 mF and 1,3 mH. In the off state, the SPS-M consumes only 0,648 W of BN. For one of the "Stimulation" modes in transceiver tests, three consumptions were measured (for three BN voltage values: 23 V; 27 V and 34 V, respectively on the "Neurolab-B"- LK-1: 72,45 W; 68,85 W and 68,02 W. The Neurolab-B-LK-2 protocol (for three BN voltage values: 23 V; 27 V and 34 V, respectively) records three power consumptions: 62,1 W, 62,1 W and 64,6 W. These data show a weak dependence of the SPS efficiency when changingthe BN voltage 23÷34 V. Five units have been fabricated from "Neurolab-B": laboratory sample and four flight samples — LK-1, LK-2, LK-3, LK-4 [6, 7, 9].

"NEUROLAB-B" was built by the Bulgarian Space Agency BASA, together with the German DOS-software NEURON (SpaceBit GmbH. Balin), provided by the German Space Agency DARA. This system was successfully operated for 4 years on board the Mir SS (1996–2000). The equipment was designed (Nedkov, 1993) to record the electroencephalogram (EEG) in the central scalp line (Fz. Cz. Pz). val and horizontal electrooculogram (EOG), skin conductance (SCL/SCR) (tonic and phase), peripheral digital skin temperature, electromyogram (EMG. forearm rigid, muscle extensor digitorum), pulse transit time (PTT) to the finger of the right hand (plethysmography), electrocardiogram (ECG), blood pressure (hand cuff, oscillography), respiration (thoracic impedance method) and voice parameters" [10].

3. Space medicine equipment on board the Russian sector of the International Space Station

Space medicine is a field of biomedical research and technology that studies human interaction with the factors of space (weightlessness, cosmic radiation, artificial environment in a hermetically sealed spacecraft). It is an important element of the practice of manned spaceflight and defines the state of the art and the prospects of human space exploration. The main areas of research in space medicine are [12]:

- Space physiology [14];
- Medical provision;
- Radiation Safety.

Prospective research is the development and creation of:

- Means for medical observation of astronauts;
- System for on-board monitoring, diagnosis, prevention and correction of the mental state of astronauts;
- System for selection and training of astronauts for interplanetary expeditions;
- On-board simulator to support operator activity.

3.1. "NEUROLAB-2000M" complex

In 1998, an experimental sample of the psycho-diagnostic complex-simulator "NEVROLAB-2000M" was developed by scientists of IMBP and RKK "Energia" and delivered on board of Mir SS and then to the International Space Station (ISS), Fig. 7a [12]. It has been used since 1998 to conduct 29 studies involving 6 astronauts on the Mir SS and ISS [12]. With this simulator crew members simulate docking and redocking of the Soyuz transport ship and the ISS.

Experimental data showed that the use of the simulator was effective in regaining lost professional docking skills in spaceflight. Test "Manometers" [11], was implemented on the basis of the instrumentation complex "Neurolab-2000M". It aimed at establishing correlation relations of indicators characterizing the quality (speed and accuracy) of the astronaut's operator activity. It is intended for the study of the processes of information perception and decision-making in conditions of strict time limit [12]. The 2011 space experiment (SE) "Pilot" aimed to investigate individual psychophysiological state regulation and occupational performance reliability of astronauts in long-duration spaceflight [12].

The first SE "Virtual" [12] started in 2013 during the flight of the crew of ISS-37/38 of Ryazansky S. N. and Kotov O. V. on board the Russian sector of the ISS (RS ISS) on (Fig. 7a). The state of the vestibular function of the astronauts after 2 days on board the ISS was observed. The second stage of "Virtual" was launched in 2015 and aimed at the following:

• Studying the effect of weightlessness on visual tracking accuracy and speed performance

• Investigating the impact of visually induced illusions (veccia) in weightlessness on visual tracking accuracy and speed performance;

• Study of visual tracking characteristics in relation to vestibular function status during weightlessness.

The third stage of SE "Virtual" consisted of performing a set of computer tests to study oculomotor responses to visual stimuli — a dot target up to 1° in size (a feedforward stimulus) moving according to a given law both on the non-oriented field of the screen (virtual reality goggles) and against the background of additional retinal optokinetic stimulation — blurred spots (ellipses) displayed on the background of the screen. An RSE Med laptop is used to record eye movement using electro-oculography and virtual reality goggles for visual and auditory stimulation. The start of the SE "Tracking" is planned for 2015–2016.

Fig. 7a. "Virtual" Space Experiment, "NEVROLAB-2000M" complex, 2013 http://vestibularlab.ru/wp-content/uploads/2013/09/History-10-2.jpg

Fig. 7b. "Pilot-T" experiment, "NEIROLAB-2010" complex https://www.energia.ru/ru/iss/researches/images/human24_1.jpg

3.2. "NEUROLAB-2010" complex

Since 2014, the first stage of the SE "Pilot-T" has been underway on the ISS RS. The model of the operator's professional activity is the Six-degrees-of-freedom (6df) program, which simulates manual control of objects with six degrees of freedom and which contains secondary cognitive tests. The qualitative parameters of the occupational activity are compared with the physiological parameters obtained using the hardware complex "Neurolab-2010". An electrocardiogram; pulse wave, electrical resistance and skin temperature of the little finger (left) and a speech signal were recorded using "Neurolab-2010". Currently 16 astronauts have completed the full cycle of the experiment [15].

The study is being conducted from 2015 to 2018, with the crews of Expeditions 43/44-53/54 (13 astronauts) participating in the study. During the flight: 43/44-50/51 ISS-Pilot-T CE is conducted twice a month, and for 51/52-53/54 ISS expeditions - once a month [15].

The SE "Pilot-T" experimental study (Fig. 7b) on board the space stations is designed to assess the expected reliability of cosmonauts during manual docking of the Soyuz or Progress spacecraft (Mir SS and ISS, respectively), [13]. For the SE "Pilot", the following equipment is used: the "Neurolab-2010" complex in the first and second stages; "Neurolab 2010+" in the second stage; a laptop in the second stage; control handles "6df" and "Virtual H"; software "6df" and "Virtual H".

3.3. "Sensomotor" set

In SE "Tracking", visual and manual tracking of astronauts in weightlessness is performed. Eye tracking, sensory interactions, stability of adaptive changes during short- and long-term spaceflight are investigated [13]. The kit consists of: a "Sensomotor" device with dimensions: 170x150x70 mm and weight 1 kg; a "Sensomotor" tablet with dimensions: 640x470x50 mm and weight 3 kg; a joystick with dimensions: 250x200x200 mm and weight 1.5 kg; a sensorimotor cart with dimensions: 300x250x190 and weight 0.3 kg; a "Sensomotor Data" device with dimensions: 70x30x10 and mass 0.1 kg [16].

3.4. "Pneumocard" complex

It has been used to investigate the influence of long-duration spaceflight factors on the autonomic regulation of blood flow, respiration and contractile function of the heart [12]. During the expeditions from ISS-14 to ISS-28, 94 experimental sessions were conducted and 19 Russian cosmonauts were studied. In 2012, 43 experimental sessions are planned to be conducted during the main expeditions ISS-30, ISS-31/32 and ISS-33/34. The planned completion date for the flight realization of the Pneumocard space experiments 2013. The kit consists of:

the Pneumocard kit 220x220x50 mm, 1.20 kg; consumables (electrodes and wipes) 0.15 kg; data card; ThinkPad A31p RSE-Med medical support laptop [16]:

3.5. "Pulse" Set

It is a computer system for monitoring the state of the cardiovascular system in weightlessness and is used for the Pulse KE for new scientific data on the mechanisms of adaptation to prolonged weightlessness, 2007 [16]. The Typology KE investigates the topological characteristics of the operator and the topological features of the operator activity of ISS crews during long-duration spaceflight [13].

The composition of the "Pulse" kit is [16]:

•Electrocardiogram (ECG), pneumotachogram (PTH) and sphygmogram (SFG) recording kit including: pulse device; ECG reading device (DUT); USI PTH; USI SFG; data cable and belt.

•On-board computer and special software.

•Sphygmomanometer TENZO PLUS (standard equipment on ISS RS).

•A "PULS" package designed to provide the experiment with consumables (electrodes, wipes, batteries, magnetic carriers).

Characteristics of instrumentation and equipment used. The "PULS" device has an autonomous power supply sufficient for 4 experiments. The device works with the on-board computer, transmitting information to it via a standard RS-232 port.

Conclusion

A high lifetime SPS was synthesized for the "Zora" system consisting of: a laptop, a microprocessor system, and medical amplifiers for complex neurophysiological testing. The applied transistor connection scheme reduces the EMC level. Appropriate structuring of the SPS ensures low noise in the analog medical data. For "Neurolab-B" system, parameters and timing diagrams were tested in different modes for the different consumers of the system: laptop; physiological signal amplifier boards; air compressor motor and hard disk. As a result, an SPS tailored to the specific parameters of the "Neurolab-B" was built. By the usage of the fans, the weight of radiators has been reduced and the SPS resource has been increased. After an electromagnetic compatibility analysis in the on-board network, an electromagnetic compatibility filter was designed and added to the SPS. The operation of the SPS in four units of "Neurolab-B" system for more than 4 years has proven stable operation in four locations: on-board the Mir SS and in the cities of Moscow, Berlin and Sofia. After the completion of the experiments with the "Neurolab-B" system, 4 new space SPS have been developed and constructively built on a modular principle at SRTI-BAS, [17–20]. They are applicable to both space physics and space medicine. These new SPS are without fans and heat sinks, which significantly reduces their weight and volume.

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СИСТЕМИ ЗА ВТОРИЧНО ЕЛЕТРОЗАХРАНВАНЕ НА УРЕДИТЕ “ЗОРА” И “НЕВРОЛАБ-Б” – КОСМИЧЕСКА МЕДИЦИНА

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Резюме

Приборите “Зора” и “Невролаб-Б” решават проблеми, свързани с изучаването, контрола и прогнозирането на здравето на астронавтите. Приборът “Зора” е компютърна система за събиране и обработка на данни от сложни неврофизиологични експерименти: “Статокинетика”, “Лабиринт”, “Потенциал”, “Свободно време”, “Въпросителна” и др. Системата за комплексно изследване на психофизиологичното състояние на космонавтите “Neurolab-B” се използва за научни експерименти с помощта на редица международни екипажи. Предложени са инженерни решения в съответствие с изследваната специфика на захранваните устройства. И двете системи са работили на борда на космическата станция “Мир” - “Невролаб-Б” от 1996 до 2000 г. Разгледани са нови инструменти за космическа медицина, използвани в руския сектор на международната космическа станция. След 2000 г. в Института за космически изследвания и технологии – Българска академия на науките, са разработени четири нови системи за вторично захранване на космически прибори. Те са приложими както в космическата физика, така и в космическата медицина.