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Automated Electronic System for Experiments with Stress Loadings by Hypergravitation

J. Přibil, I. Frollo
Institute of Measurement Science, Slovak Academy of Sciences,
Dúbravska cesta 9, SK-841 04 Bratislava, Slovakia, phone: +4212 5910 4543, e-mail: umerprib@savba.sk
R. Kvetňanský
Institute of Experimental Endocrinology, SAS,
Vlárska 3,SK-833 06 Bratislava, Slovakia, e-mail: ueenkvet@savba.sk
M. Juráni
Institute of Animal Biochemistry and Genetics, SAS,
Moyzesova 61, SK-900 28 Ivanka pri Dunaji, Slovakia, e-mail: ubgzgrek@nic.savba.sk

Introduction

One of the serious problems of cosmic flights is an effect of mechanical forces on the living organism, the gravitational forces, influence of the pressure above and below atmospheric, hence the overload of a living organism, human, or animal during the start and landing of a spaceship. The gravitational force for the human being is an ally and an enemy at the same time. On the other hand, no life would exist on the Earth without gravitational force.

There are still unanswered questions by scientists, how the overload is influencing the living organism just during start, or landing. The influence of the gravitation overload on a man exhibits a row of physiological changes on psyche, on the body mass, on the body shape, on the blood circulation changes, in the blood structure, on the respiration. The blood circulatory system is the most impacted. Malfunctions of the brain and heart can arise.

However important is not only the overload value but also a duration of this overload. The open question is how to test these parameters, how to prevent them and how to prepare the incoming astronauts during the training for the fact, that during the start or landing some physiological failures can appear, [1]. Humans to maintain terrestrial physiologic functions in space need to create an artificial gravity in a space station. Using a centrifuge a gravity equivalent to that of Earth can be produced in space [2].

The actual conception and development of a centrifuge for hypergravity research use was described in [3] and [4]. The living organisms on the Earth live under the influence of the gravitational force of the Earth which produces an acceleration of $9.81 m/s^2$ indicated by the symbol g. The unit of the ratio of an applied acceleration to the gravitational constant is conventionally called G, and calculated by the expression: G = applied acceleration/g.

Our equipment described in this article serves for implementation of series of experiments on small animals that are subjected by hypokinesis or hypergravitation during different time intervals. The instrumentation is equipped by telemetric control system for programmable blood collection using cannulation from experimental animals located in hypokinetic boxes or on a centrifuge. The goal of experiments is monitoring of an influence on blood properties during different gravitational overload values *G*, evaluation of hormone levels, neurotransmitters and metabolism [5]. Results serve for evaluation of living organism ability to overcome the stress load. The equipment can be used also for study of microgravity effects in the animal organism during space flights for the understanding of the mechanism of the activity changes of neuroendocrine system and metabolic processes.

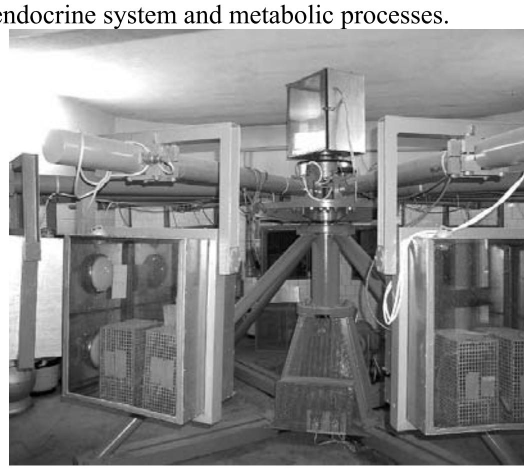


Fig. 1 The centrifuge device construction

The short time (up to two hours) and the long time experiments (up to one or two weeks) are performed on this device. Animals are divided to two groups – tested ones are placed in the cabins attached at centrifuge arms and the second group is placed on the floor of centrifuge room for comparison. Only the stress factors (noise and vibration of device, light, and temperature) have influence on this group of animals, not the gravitation force. All animals had inserted polyethylene tubing in the tail artery, which was connected with a pre-programmed device for three blood withdrawals (0.5 ml each) into individual syringes, performed at any time intervals. We have done blood sampling at various time intervals of different hypergravity.

Electro-mechanical equipment

Whole electro-mechanical equipment of centrifuge is placed in a laboratory of the Institute of Animal Biochemistry and Genetics, SAS in Ivanka pri Dunaji, near Bratislava.

The rotation part of the centrifuge consists of 12 arms with hanged cabins and one on the top. Rotation of cabins is controlled by the electric drive based on intelligent DC inverter connected via serial line with the PC computer [5].

In practical experiment, the current value of gravitation force G in cabins must be known. For measurement of the instantaneous gravitational force an accelerometer was used, but a problem with telemetric data transmission and processing in consequence of strong el. mag. interference produced by centrifuge electric drive occurred.

Another measuring method is based on the knowledge of rpm (revolutions per minute value) of the centrifuge vertical axle (n_{cfg}) and the length of centrifuge arm where the cabin is mounted or the centrifuge radius). The value of centrifuge rpm can be derived from main motor drive revolutions n_{mot} (after multiplication by the gear ratio). However, there exist large belt slip between the gearbox and the centrifuge vertical axle. The slip effect brings a considerable inaccuracy in determination of the n_{cfg} values, the result of calculated of gravitation force G has not quite correct values and makes the method practically unusable.

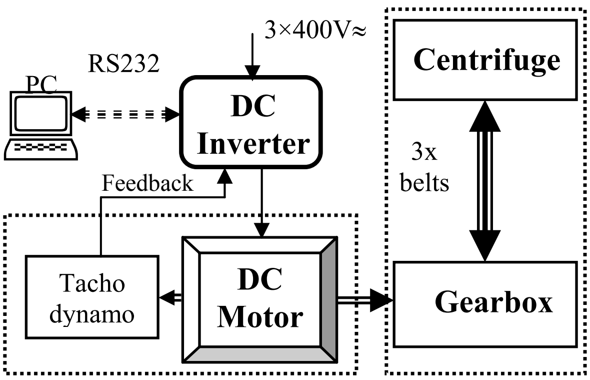


Fig. 2. Block diagram of centrifuge electric drive

We can also measure directly the of n_{cfg} values. In our case, the applied method for measuring the real revolution of centrifuge was using the non-tactile optoelectrical sensor as the rpm-to-frequency (n/f) converter [6]. Output rectangle impulse signal of the sensor was transferred to the operating room by coaxial cable to minimize the el. mag. interference noise. For this reason the optoelectrical sensor has separate 24V= power supply. In the operating room the signal from sensor is connected to the frequency-to-voltage (f/U) converter, output voltage signal is further fetched to the 12-bit A/D converter located into DC inverter MENTOR II which is at the same time used for power supply of all components [7].

Measured data signal from the inverter is transmitted via serial connection to the control PC computer, which performs the final operation (see control panel of centrifuge main motor drive application in Fig. 3) – evaluation and visualization of gravitation force G values actually reached in the cabins of the centrifuge.

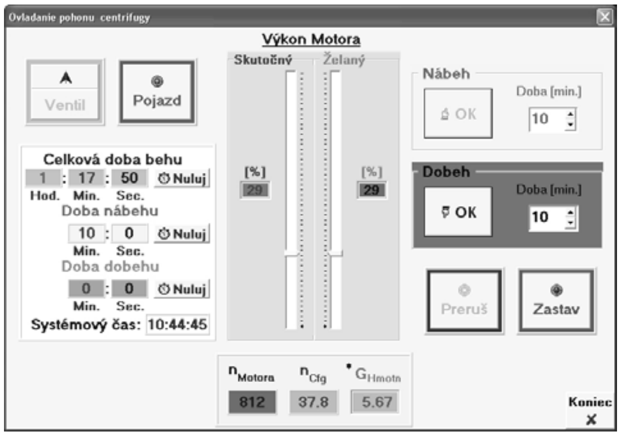


Fig. 3. Centrifuge main motor drive control panel

From the measured frequency characteristic of the optoelectrical sensor and the calibrated conversion characteristic of the f/U converter the multiplication constant k_s was specified

$$n_{cfg} = f(U_{out} \cdot k_s), \qquad k_s = 0.6744 \tag{1}$$

and revolution characteristic was determined.

From obtained n_{cfg} values three types of calculation can be subsequently performed:

1. calculation of centrifugal force F_{cfg}

$$F_{cfg} = \omega^2 \cdot r = \left(\tfrac{2\pi}{60}\right) \cdot n_{cfg}^2 \cdot r, \tag{2}$$

where r is the centrifuge radius in [cm] and n_{cfg} is the centrifuge rpm.

2. Calculation of achieved gravitational force G (gravitational overloading) in the interval of $G \in <0 \div G_{max}>$

$$G = \tfrac{F_{cfg}}{g} = 1.117 \cdot r \cdot n_{cfg}^2 \cdot 10^{-5}, \tag{3}$$

where g is gravitation constant equal to 9.80665 ms^{-2}.

3. Determination of result impacting gravitational force G_{wgh} (weight overloading) – giving the multiple of the original animal weight in the interval of $G_{wgh} \in <1 \div G_{max}>$

$$G_{wgh} = \sqrt{g^2 + G^2}. \tag{4}$$

Distributed blood-withdrawing system

The blood withdrawing of tested animals (time and volume) can be also controlled from main computer, with the help of a radio frequency (RF) command system. Each of the animals is connected to four syringes (three for blood withdrawing and one with heparin used as the protection to blood coagulation in cannulas see Fig. 4) driven by two stepping motors.

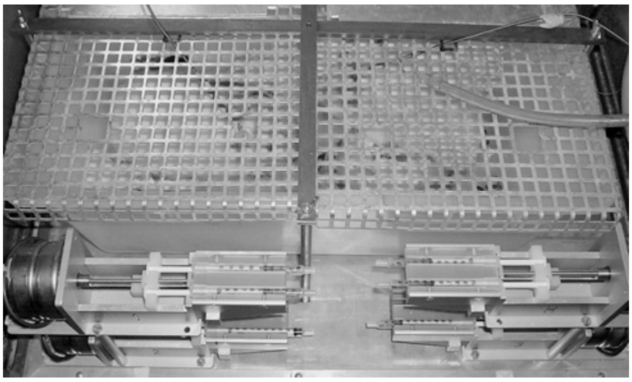


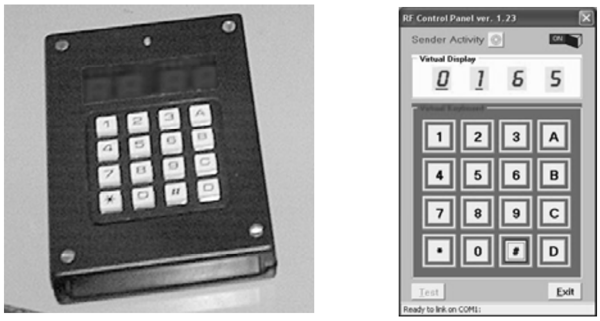
Fig. 4. Interior of a centrifuge cabin for testing of two experimental rats with a blood-withdrawing device

The RF command system consists of one transmitter and two data signals receivers (the first one is for tested animals in rotating cabins on the centrifuge; the second is used for stationary – comparison - group of animals). The transmitter, placed in the centrifuge operating room and both receivers, are working on frequency of 433.92 MHz using modulation ensuring high immunity towards malfunction based on the hybrid modules AUREL: TX-SAW 433s and STD 433 DIL. Two versions of transmitter controlled by microcontrollers were realized:

- a portable type with a keypad and display powered by battery (see Fig. 5a) used for manually settings the blood withdrawing sequence,
- in the form as the external unit connected via serial RS232 port to the main control computer, powered also from this computer (see dialog window of control panel in Fig. 5b).

Receivers, also controlled by microcontrollers, are connected through cables with step motors placed in every cage driving the syringes. After switching on it is waiting for a radiofrequency signal comprising pre-programmed sequence. After a LED diode is confirming the successful receiving, the count down is starting and the applied sequence is starting. The receiver is switching on the selected driving rods of syringes in precise time moments. After sequence is finishing the syringes are removed and using manual control (pushing button) the driving rods are returned to the initial position.

The command system enables pre-program sequences t0, q0, t1, q1, t2, q2, (see Fig 6). It is possible to set up width of pulses, their time schedule *t* and blood volume *q* values.



a) b)

Fig. 5. Implementation of RF command transmitter: a) portable device, b) dialog window of software control panel

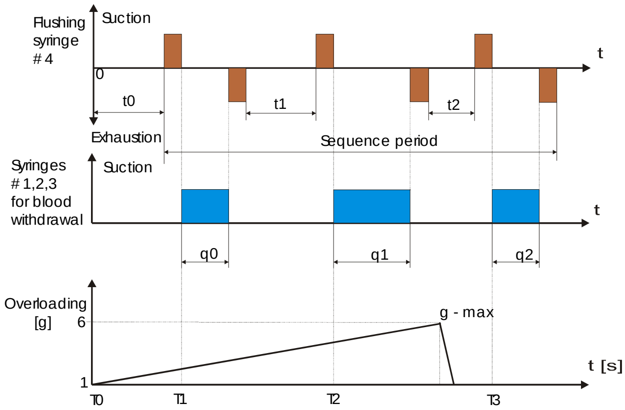


Fig. 6. Programmable sequences example for blood withdrawing

Thermo stabilization system for blood storing

Tested animals must live in boxes with constant temperature about 30 °C bringing a problem with usability of blood samples in the case of long time experiments. This is the reason why the thermo stabilization system for blood was developed. Realized system holds the blood samples in the temperature interval 4 ÷ 10 °C for the duration of the several-days experiments. In the design of the thermo stabilization system for blood cooling and storing, the following criteria must be fulfilled:

- Thermo stabilization system works autonomously independent from the automated blood withdrawing and centrifuge drive control system.
- System will work in an environment with a strong electromagnetic disturbance generated by a tyristor DC inverter used in the centrifuge motor drive.
- Autonomous system must work with maximum reliability without servicing of operating staff (during the experiments, while the centrifuge rotates, the human entrance to the centrifuge room is forbidden).
- The blood temperature long time stability during one or more week's experiments.

For the practical realization of the blood cooling system, we decide to use the approach based on the Peltier thermoelectric device [9]. As followed from our another cooling experiments, the basic air cooler was not sufficient in the case of higher values of power current by the Peltier element (needed for acquirement of requested minimum temperature) commonly with the higher ambient air temperature. Therefore, we use the liquid cooling system, which is originally used in computers for cooling of the main processor unit. The blood filled up syringes in the aluminum block holder (see area A on Fig. 7) are attached on the cool side of the Peltier element (area B), the warm side is attached on copper water block of liquid cooling system (area C). Completely thermoelectric device is supplied from the ≈24V-power distribution on the centrifuge arms used also for cabin interior lighting. The 10A-switch regulator based on the integrated circuit L497A powers the Peltier device M-TEC1-12710 with total load of 89 W.

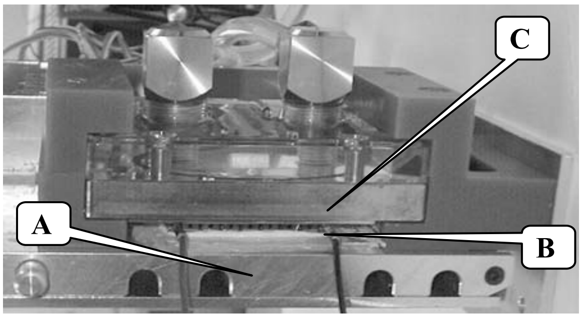


Fig. 7. Mechanical construction of Peltier cooler system: aluminum block holder for blood bleeding injections (A), Peltier device (B) and cooper water block (C)

Because the thermo stabilization system will work autonomous, we need to have sufficient information about actual temperature on the warm and cool side of the Peltier element. Therefore, designed thermo stabilization system contains enough three thermoelectric sensors:

1) The bimetal thermal fuse ETF1 installed inside the copper water block for emergency stop in the case of fatal function error (when the temperature is over 75°C).
2) Thermoresistor ThR1 of the series KTY81 (thermo positive – TPC) allocated also in warm side of Peltier element, used for disabling power supply of the Peltier device, when the temperature is over 45°C (in the case of non fatal function error).
3) The second thermoresistor ThR2 installed in the aluminum holder is intended for temperature monitoring of the blood filled up syringes. When the actual temperature lies bellow 6 °C, the supplying of the Peltier cooler is switched off, when the temperature is over 6 °C, supplying is switched on (the water pump and cooling of the radiator is running all the time).

Each of two thermoresistors was a fundamental component of the temperature-to-frequency (T/f) converter based on the oscillator circuit NE555. Output frequencies in total range of 5 ÷ 10 kHz are after dividing connected to the comparison blocks, which produce output signals for the control logic part. These two signals are evaluated in f_{norm} clock time interval and control voltage (on/off condition) for switched power is generated. Emergency thermal fuse ETF1 can disconnect the main power supply for Peltier device in the case of too high temperature on the warm side of the element – see Fig. 8.

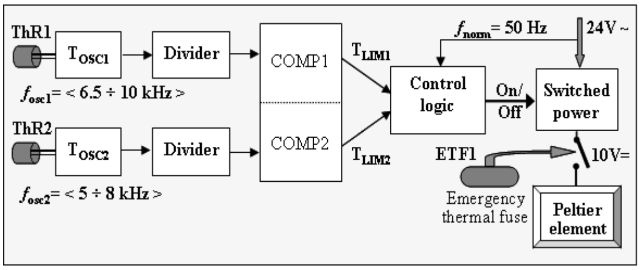


Fig. 8. Block diagram of used temperature stabilization method

Experiments and results

Due to the great inertial mass of the whole rotation parts of the centrifuge, the process of starting and stopping lasts several minutes and also the centrifuge revolutions fluctuate very slowly. Hence, the time interval of reading the values from A/D converter to the control PC computer was set to $T_{load} = 5$ s. In the rhythm of this interval the current value U_{out} was received, relation (1) counts the centrifuge revolution, while the accuracy of gravitation force G calculation depends on the correct determination of the centrifuge rotation n_{cfg}. Therefore, the control measurement of the centrifuge rotation was performed with the help of a digital photo tachometer. The measurement shows good agreement of obtained values with verified non-tactile optoelectrical sensor [8].

In practical experiments the maximum value of G=7 calculated by (1) and (3) has been achieved. The measured gravitation characteristic obtained from these experiments is shown in Fig. 9.

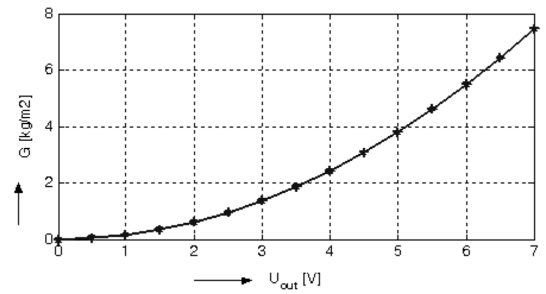


Fig. 9. Resultant centrifuge gravitation force characteristic

During the proving test of the centrifuge drive the next unfavourable effect occurred. In dependence of a slip effect a gear and belts are warming, which in the finally state causes belts lengthening and subsequently next increasing of slipping. This physical effect can not be eliminated, but some correction technique must be applied. In Fig. 10 there is a comparison of measured centrifuge revolution characteristics obtained after "cold" and "warm" start (directly after approx. 2 hours operated centrifuge with reached G = 2). From this comparison follows, that in the second case the higher value of the main motor drive revolution n_{mot} is necessary for achievement of the equivalent value of the gravitation force G.

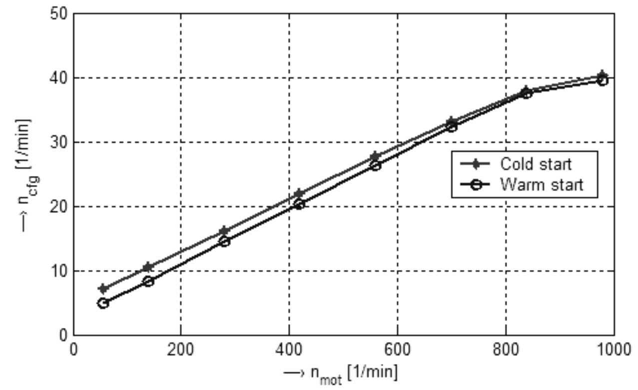


Fig. 10. Influence of heating of mechanical parts of the centrifuge

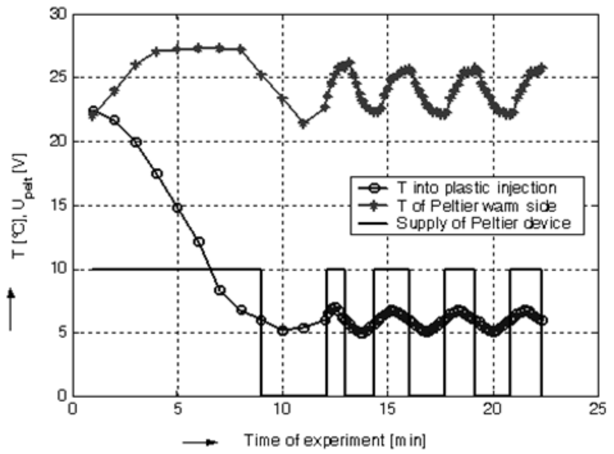


Fig. 11. Short time regulation characteristics of blood thermo stabilization system

The regulation characteristics of blood thermo stabilization system was measured and tested with proper function of water-cooling system, the operating temperature limit was set to the 6 °C (see Fig. 11). During the reaction time of initial cooling phase the temperature was measured in minute intervals, after first switching-off the Peltier supply the temperature was measured in 10 sec intervals (the values are changed slightly).

Conclusions

The centrifuge drive system disposes with a considerable reserve of the power ($P_{total} = 10$ kW) and the revolution ($n_{mot} = 0 \div 1000$ min^{-1}) of the main drive motor. The necessary motor revolution n_{mot} for achievement of the maximum gravitation force value $G = 7$ lies near the value $n_{mot} \approx 1000$ min^{-1} (the reaction and run down time interval for reaching this value is approx. about 15 minutes). The automated regulator included in the intelligent DC inverter MENTOR II is able to eliminate small and slow changes of centrifuge rotation, so the result value of the obtained gravitation force can be considered as a constant. After finishing of the experiment the technical pause for cooling of temperature of mechanical components must be performed, so that the start was with the same initial conditions.

The functional prototype of designed autonomous blood thermo stabilization system was realized and tested in laboratory working conditions. After testing it was mounted on the centrifuge device. From performed measuring and practical experiments follows, that system works correctly short time function tests confirm good stability in requested temperature range of 4 ÷ 10 °C. In coming experiments we will continue in testing of:

- Influence of gravitation force to the liquid pump (effectivity of the water-cooling system can decrease).
- Influence of higher temperature of ambient air in the testing cabin (in reference to testing animals will be minimum of 30°C).
- Behaviour of the whole thermo stabilization system in the course of long time experiments (long time temperature stability).

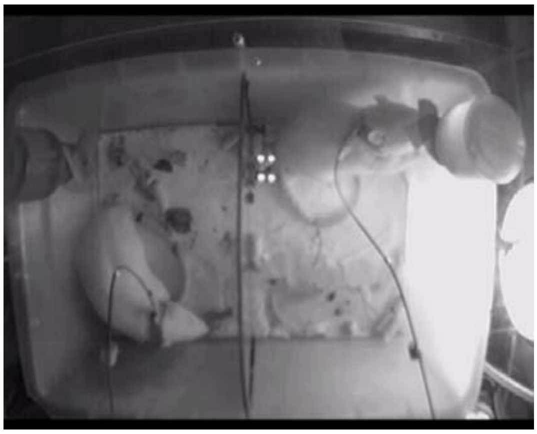


Fig. 12. View to the testing box with two cannulated rats during the starting phase of centrifuge rotation

Test on animals has been performed successfully. In addition, it is necessary to observe behaviour of tested animals in boxes during the starting of the deceleration phase and in the phase of a constant hyper gravitation. Therefore, the CCD camera system was realised. Two cameras (which can work also in infrared mode) placed in rotating cabins transmit the video signal to the operating room by RF signal at frequency 2.4 GHz (see picture in Fig. 12). The third, stationary camera for control group is connected by coaxial cable. Obtained video signals in time multiplex can be also stored to the hard disc of main control computer.

The automated electronic system for a centrifuge for stress loadings serves for implementation of series of experiments on small animals that are subjected by hypokinesis or hypergravitation during different time intervals. The goal of experiments is monitoring of an influence on blood properties during different gravitational overload values G. Hypergravity is known to activate the sympathoadrenal system (SAS). Rats subjected to various acceleration (+G) exhibited increased levels of plasma norepinephrine (NE) and epinephrine (EPI). However, the collection of blood was performed after a centrifugation finished and therefore plasma NE and EPI levels could be affected by the process of deceleration. More experimental results on animals will be published elsewhere.

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Equipment serves for implementation of series of experiments on small animals that are subjected by hypokinesis or hypergravitation during different time intervals. The instrumentation is equipped by telemetric control system for programmable blood collection using cannulation from experimental animals located in hypokinetic boxes or on a centrifuge. The goal of experiments is monitoring of an influence on blood properties during different gravitational overload values G, evaluation of hormone levels, neurotransmitters and metabolism. Results serve for evaluation of living organism ability to overcome the stress load. One set of the equipment consists of a transmitter and receiver equipped by microcomputers, 28 pairs of active rotor stepping motors, each driving two pairs of syringes. Transmitter and data signals receivers are active on frequency of 433,92 MHz using modulation ensuring high immunity towards malfunction. The equipment is controlled by computer equipped by interactive user-friendly program. The equipment can be used also for study of microgravity effects in the animal organism during space flights for the understanding of the mechanism of the activity changes of neuroendocrine system and metabolic processes. Ill. 12, bibl. 9 (in English; summaries in English, Russian, Lithuanian).

Ё. Прибил, И. Фролло, Р. Кветнански, М. Юрани. Автоматизированная система для экспериментов со стрессовыми гравитационными перегрузками // Электроника и электротехника. – Каунас: Технология, 2007. – № 8(80). – С. 43–48.

Оборудование использовано для серии экспериментов на маленьких животных, которые подвергнуты гипокинезу или гипергравитации в течение различных временных интервалов. Инструменты оборудованы телеметрической системой управления для программируемого взятия крови, использующей систему трубок, расположенных в гипокинетических коробках или на центрифуге. Цель экспериментов – мониторинг влияния перегрузки на свойства крови в течение различного гравитационного Г, оценка гормональных уровней, медиаторов и метаболизма. Результаты служат для оценки способности живущего организма преодолеть стрессовое напряжение. Один набор оборудования состоит из передатчика и приемника, оборудованного микрокомпьютерами, 28 пар активных роторных шаговых двигателей, каждая из которых движет две пары шприцов. Передатчик и приемники сигналов данных активны на частоте 433,92 МГц и используют модуляцию, гарантирующую высокое сопротивление сбою. Оборудованием управляет компьютер с интерактивной и легкой в использовании программой. Оборудование может использоваться также для исследования эффектов микрогравитации на организм животных в течение космических полетов, чтобы понять механизм изменений деятельности нейроэндокринной системы и метаболических процессов. Ил. 12, библ. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

J. Přibil, I. Frollo, R. Kvetňanský, M. Juráni. Automatizuota sistema stresiniams gravitaciniams eksperimentams atlikti // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 8(80). – P. 43–48.

Naudojant įrangą, atlikta serija eksperimentų su mažais gyvūnais. Jie skirtinga trukme veikiami hipokineze arba hipergravitacija. Instrumentuose įdiegta telemetrinė programuojama valdymo sistema, surenkanti kraują iš eksperimentinių gyvūnų. Tam naudojama vamzdelių sistema. Eksperimentų tikslas – stebėti poveikį kraujo savybėms esant skirtingoms perkrovos G vertėms, įvertinti hormonų neurotransmiterių ir metabolizmo lygius. Remiantis gautais rezultatais įvertinamas gyvo organizmo gebėjimas įveikti stresines perkrovas. Įrangos rinkinys susideda iš siųstuvo ir imtuvo su mikrokompiuteriais, 28 porų aktyviųjų rotorinių žingsninių variklių, kurių kiekviena valdo dvi poras švirkštų. Duomenų signalų siųstuvai ir imtuvai veikia 433,92 MHz dažniu taikant moduliaciją, kuri padidina atsparumą sutrikimams. Įrangą valdo interaktyvi ir lengvai įsisavinama programa. Įrangą taip pat galima panaudoti tiriant mikrogravitacijos poveikį gyvūnų organizmui kosminių skrydžių metu, siekiant suprasti neuroendokrininės sistemos ir metabolinių procesų veiklos pokyčių mechanizmus. Il. 12, bibl. 9 (anglų kalba; santraukos anglų, rusų, lietuvių k.).

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