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EXPERIMENTAL UNIT FOR DETERMINING BODY WEIGHT OF ASTRONAUTS AND LIGHT-WEIGHT OBJECTS IN ZERO-GRAVITY CONDITIONS

Abstract. The transition of an astronaut into zero gravity leads to a certain restructuring of the body, including the redistribution of fluid flows in it. The process of dehydration of the body is stimulated, the astronaut loses weight. Knowledge of the regularities of changes in an astronaut's body weight, keeping it within normal limits thanks to a rational load distribution, rest, physical exercises, and a well-thought-out diet are extremely necessary in order to provide the astronaut with the most favorable conditions for adaptation in zero gravity, as well as to better prepare him for his return to Earth. Returning materials for scientific research and experiments, as well as equipment, from the space station to Earth also requires high-precision determination of the low weight of objects. **The object of the research** is an experimental unit that allows measuring the weight (parameters) of the astronaut's body and the small weight of objects (equipment, devices, etc.) that oscillate. **The subject of research** is the frequency of natural oscillations of the dynamic system. **The purpose of scientific work** is the development of an experimental unit for determining the weight of the astronaut's body and the low weight of objects in zero gravity. **Conclusions.** An experimental setup for determining the body weight of astronauts and the low weight of objects (control objects – CO) in zero gravity is proposed. For high-precision determination of the weight of the CO in zero gravity, the natural frequency (NF) was chosen as a diagnostic parameter. In the experimental installation, the weight of the OC is determined by changing the NF of the dynamic system "control object – moving anchor" depending on the attached weight of the CO. The essence of the work of the experimental unit is revealed, and its general appearance and structural scheme are presented.

Keywords: zero gravity; astronaut's body weight; low weight of objects; object control; experimental setup; natural frequency; dynamic system.

Introduction

It is known that the weight of an object (body) arises as a result of the Earth's gravity, but may differ in magnitude from the force of gravity. In particular, the ratio between the gravity force acting on an object and the weight of the object changes as soon as the support (ground) begins to move up or down. In this case, the weight of the object will not be equal to the force of gravity.

Consequently, the state of a body (astronaut or object) in which it has no weight is called zero gravity (zero-gravity). This state occurs when the body and the support on which it is located are free-falling. In a free fall of a body with a support, there is no interaction between them, the body does not press against the resistance and no deformation occurs, and therefore there is no reaction force of the support and the weight of the body.

The state of zero gravity occurs in astronauts and objects on board of a spaceship with the engines turned off, as a result of which they float freely in the cabin (Fig. 1). At the same time, the bone density of astronauts in the state of zero gravity decreases by more than 1 % per month. For comparison, the loss of bone weight in old age is from 1 % to 1,5 % per year.

Astronauts in zero gravity do not exert much effort, which causes muscles to lose strength quickly over time. Stamina and volume, respectively, change the weight of astronauts.

In addition, the return from orbit to Earth of research and experimental materials, as well as malfunctioning equipment, all require highly accurate weight determination.

Consequently, determining the weight of the astronaut's body and the small weight of objects (equipment, devices, etc.) in zero gravity is an urgent scientific and practical task.

Thus, it is necessary to develop an experimental setup for high-precision determination of the astronaut's body weight and small weight of objects (equipment, devices, etc.) in zero gravity.

Fig. 1. Astronaut and objects in a state of zero gravity on the ISS

Research results

The choice of this parameter for other parameters is due to the fact that it is easier to analyze the parameters that characterize the elastic oscillatory motion of the dynamic system – dynamic parameters.

The greatest information about the state of the dynamic system is carried by the following parameters, included in the vector of analyzed dynamic characteristics:

- frequency of natural (auto-resonant) oscillations (w);
- logarithmic decrement of oscillation (δ);
- absorption coefficient (ψ);
- kinematic characteristics of oscillatory motion (displacement, velocity, acceleration);
- a number of parameters of nonlinear vibrations;
- resonance amplitudes.

The selected control parameters in total contain complete information about the specifications of the dynamic system. However, the practical implementation of all these parameters to determine the specifications of the dynamic system is associated with a number of important difficulties.

First of all, it is the complexity associated with the control and the equipment used, its large weight and dimensions. Application of this equipment requires significant labor costs and time to perform a given volume of tests, conditions of its placement on board of the orbital station, where the amount of living space is limited. The degree of influence of parameters of the control object (CO), associated with the dynamic system on the specifications of the output signals will be different. In this regard their definition will be complicated. And this, in turn, will affect the information value of the output signals.

Therefore, in practice it is necessary to use the parameter, which is able to carry the most information about the oscillating system. Auto-resonant oscillations can be used as such parameter.

Agitated in an appropriate way (non-contact method) undamped harmonic oscillations of the dynamic system with natural frequency (NF) can be perceived by oscillation sensors and converted into an output signal acceptable for the perception of control equipment (peripheral device).

In case of harmonic auto-resonance agitation of oscillations the stability of vibrating system can be assured by magnetodynamic compensation of application of dissipative forces, and linearity of elastic characteristics of oscillating system – by selection of appropriate level of agitation.

Consequently, only the NF can be used as a diagnostic parameter, because in comparison with other characteristics it has the following advantages:

- high stability;
- ease of measurement;
- high accuracy of its measurement (with an error margin not exceeding ± 0,01 %).

NF, as a defined control parameter, meets the requirements of operability to the highest degree. On the modes of self-oscillation such characteristics as NF can be obtained more easily.

Judging by changes in the NF spectrum, we can immediately answer the question, for example, in regard to changes in the weight characteristics of the dynamic system "control object – moving anchor". The spectrum of NF can be increased by changing the stiffness of the elastic elements that make up the dynamic system "object of control-moving anchor".

The essence of the NF control method used to determine the body weight of the astronaut and low weight in zero-gravity [13] is based on the change of parameters of natural vibrations of dynamic system (natural frequency and amplitude) from the weight of CO attached to it.

In each given case, the behavior of the dynamic system of the experimental setup during free harmonic oscillations characterizes its dynamic individuality. It consists in the inherent distribution of weight and stiffness characteristics.

The attached to the "movable anchor" CO having the corresponding weight and increasing the rigidity parameters of the dynamic system by compression of the elastic elements (springs), entails the change in the properties of vibrations of the dynamic system.

Provided that the initial value of NF for the dynamic system of the experimental setup without the attached weight of the CO at certain values of compression of the elastic elements of this system is known, then by measuring the NF during the control of the object weight and comparing them with the calibration graphs obtained earlier with the reference ones, we can determine the OC weight.

The experimental setup for determination of an astronaut's body weight and small weight of objects in zero-gravity conditions is intended both for weight determination in normal (terrestrial) conditions and in zero-gravity conditions (including space orbital stations or special-purpose aircraft in orbital flight).

Determination of weight is carried out by changing the NF of the dynamic system "control object-moving anchor" depending on the attached weight of the OC (study).

The received information about the NF is output to the electronic frequency counter (EFC) for subsequent data entry into the computer. The dynamic characteristics of the system in the computer are translated into the dimensions of the weight with subsequent output of the information to the peripheral device (for example, to the control and recording equipment).

The general appearance of the experimental installation is shown in Fig. 2, 3, and its structural diagram is shown in Fig. 4.

Constructive implementation of an experimental unit for determining the weight of the astronaut’s body and the low weight of objects in zero gravity. The experimental unit (Fig. 4) consists of the following main parts:

- housing with auxiliary structural elements;
- magnetodynamic oscillation agitation system made in the form of electromagnets (EM);
- a movable ferromagnetic anchor with a fixed permanent magnet (N/S);
- induction sensors;
- base (for mounting the control object);
- elastic elements (EE).

Composition of the experimental unit. Structurally, the experimental setup also includes an EFC (for recording the NF of the dynamic system), a computer and a low-frequency amplifier (LFA).

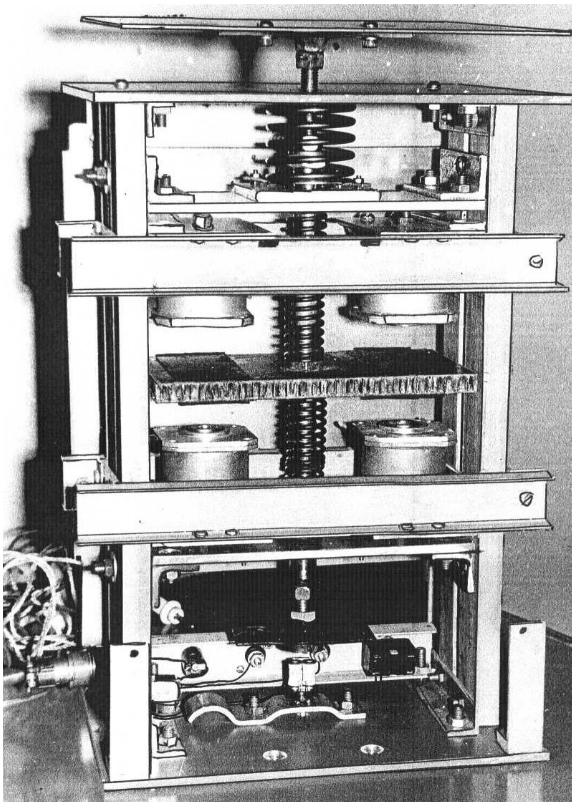

Fig. 2. General view of the experimental unit (with the back cover removed)

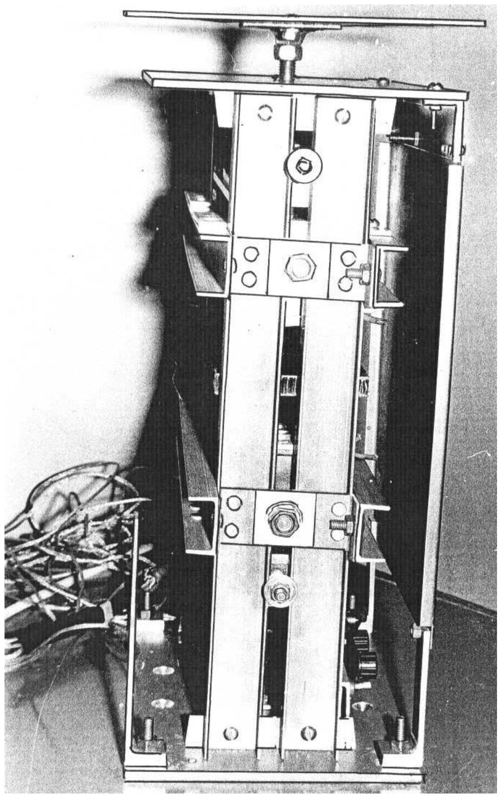

Fig. 3. General view of the experimental unit (with the side cover of the case removed)

The case with auxiliary structural elements (on which EMs are attached), elastic elements (springs), a movable ferromagnetic anchor with a permanent magnet attached to it, an induction sensor located in the magnetic field zone of the permanent magnet, form a device for determining the weight of the attached CO. The auxiliary design elements of the experimental setup, which are designed to move the EM relative to the ferromagnetic linings of the "moving anchor", change the gap between them by compressing the springs, which ensures an increase in the stiffness of the dynamic system.

EFC (and computer) constitute a system of control and recording equipment and information (Fig. 4).

Structural and composition scheme of the experimental unit. The structural and composition scheme of the experimental unit is shown in Fig. 5.

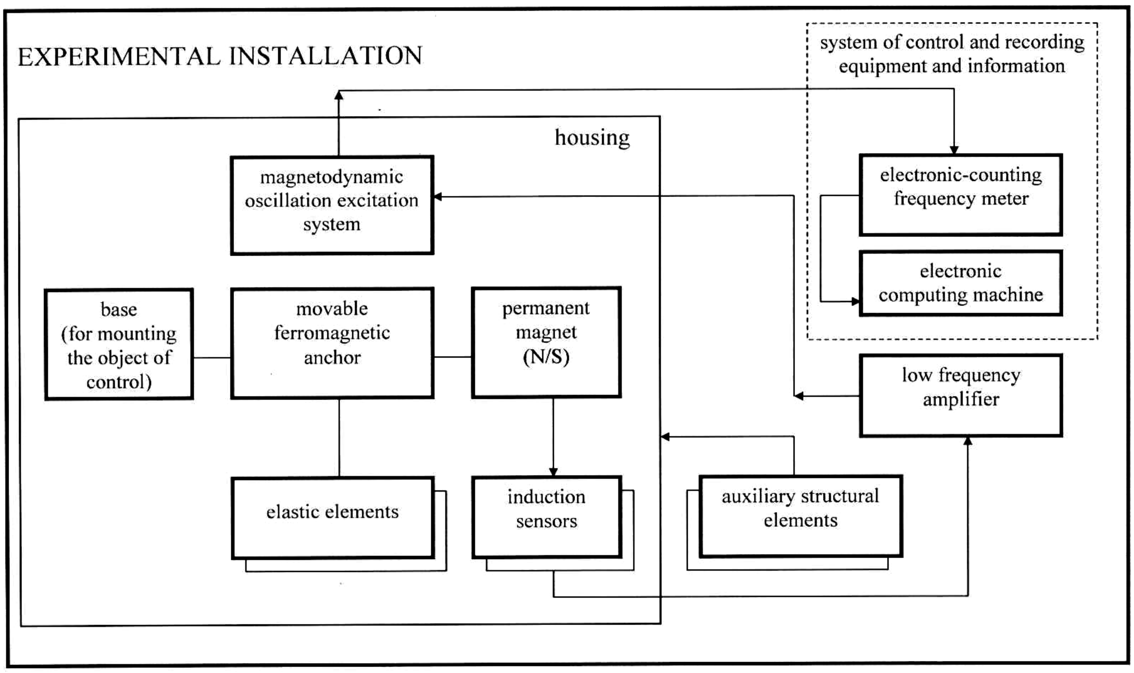

Fig. 4. Structural diagram of the experimental unit

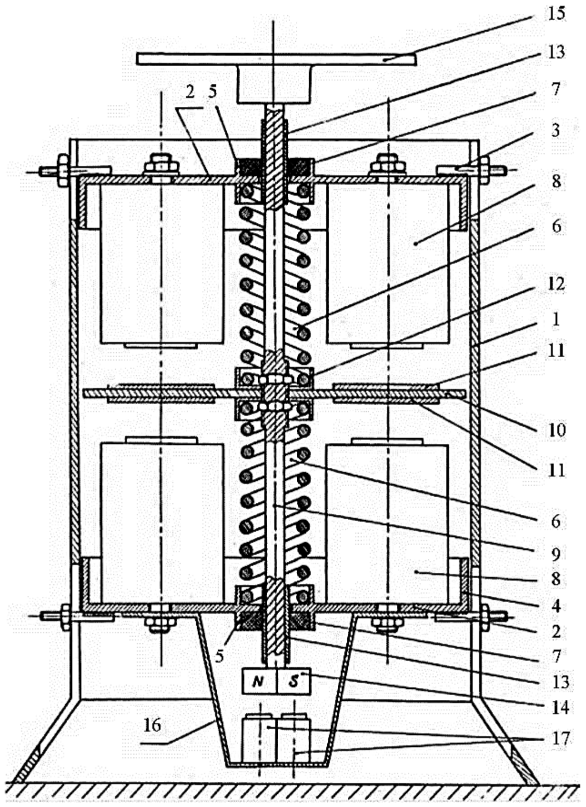

Fig. 5. Structural and composition scheme (variant) of the experimental unit

Design of the experimental unit. The experimental unit consists of (Fig. 5): the body (1) and the movable covers (2) with the fixing nodes (3) of the covers passing through slots in the body (1). Each cover (2) has a flap (4) to ensure the possibility of moving the cover (2) inside the body (1) without distorting it. Ring stiffeners (5) on cover (2) form limiters for springs (6) and a place for installing a fluoroplastic gasket (7). To the inner part of the cover (2) (in the plane passing along the longitudinal axis of the cover (2) through its geometric center "GC"), two EM (8) (which are combined into a block) are attached by means of screw fasteners, which are located inside the case (1) axisymmetric with respect to one another, relative to the longitudinal axis ("LA") of cover (2) and its geometric center ("GC") (Fig. 6).

In the geometric center "GC" of the cover (2), a hole is made (Fig. 6), through which the rod (9) passes, which has a thread cut in the central part for fastening a non-magnetic plate (10) to the rod (9) using self-locking nuts. On both surfaces of the plate (10), ferromagnetic pads (11) and limiters (12) for springs (6) are rigidly fixed (limiters (12) are ring-type).

The limiters (12) simultaneously serve to exclude the skewing of the plane of the non-magnetic plate (10) relative to the longitudinal axis ("LA1") of the rod (9) (withholding an angle of 90°). Bronze bushings (13) are mounted on the ends of the rod (9) with tension (which, when in contact with fluoroplastic gaskets (7), provide a minimum coefficient of friction between them).

A permanent magnet (14) is attached to the lower end of the rod (9), and a base ("plate 15") is attached to the upper end, which is intended for mounting the control object. A cup (16) is attached to the outer side of the lower cover (2), inside which an electromagnetic induction displacement sensor (17) (hereinafter referred to as the sensor) is placed, the output of which is connected to a low-frequency amplifier (13) (LFA) (absent in Fig. 5, see block scheme in Fig. 7).

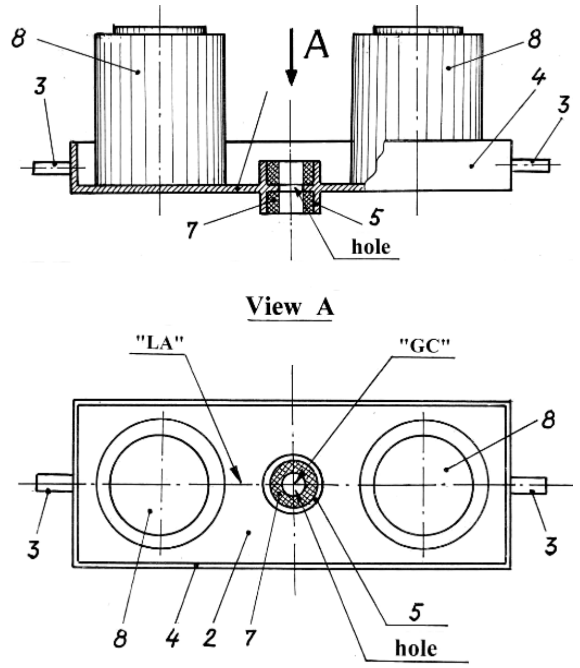

Fig. 6. A chart of fixing of electromagnets is on a lid

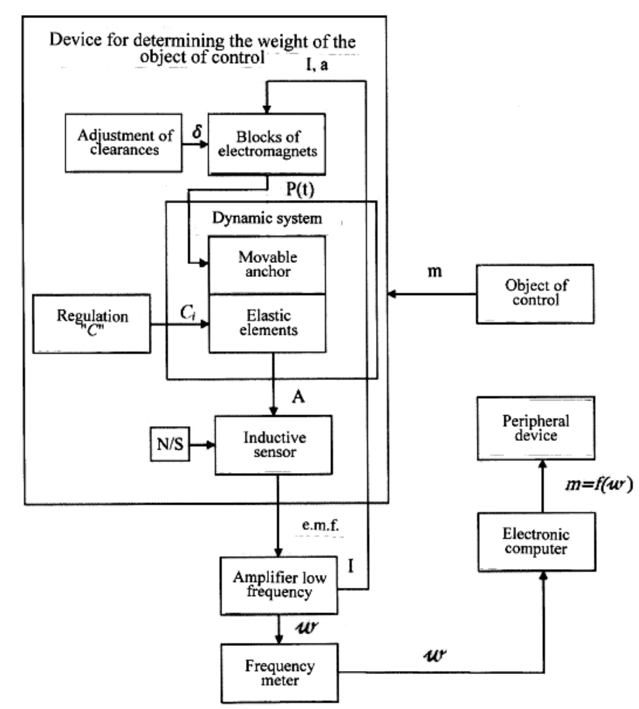

Fig. 7. Block scheme of the experimental unit

Purpose of the components of the experimental unit and their role in ensuring its operation. The rod (9) is designed to ensure the movement of the plate (10) between the EM blocks (8).

The rod (9) (with the plate (10) rigidly fixed on it) with springs (6) (of the same stiffness) located between the immovably fixed covers (2), axially symmetrical to each other and relative to the longitudinal axis "LA1" of the rod (9), create a dynamic system – the above-mentioned "moving anchor" (Fig. 4).

The electromagnetic induction sensor (17) of movement is designed to create an electromotive force (EMF) with subsequent transmission of a useful signal to the input of the LFA.

The sensor unit (17) is located in the field of a permanent magnet (14) (N/S), which has the ability to move together with the rod (9) in the vertical direction along the longitudinal axis of the housing (1).

The sensor unit (17) is a feedback sensor, the output signal of which is proportional to the speed of movement of the "moving anchor". Some non-linearity between the voltage removed from the sensors (17) and the force developed by the EM (8) occurs due to the fact that the force of the EM (8) is proportional to the gap between the "moving anchor" and the stationary parts of the magnetodynamic system. This helps to stabilize the amplitude of oscillations. Thanks to this, during the long-term operation of the MDOA system, an unlimited increase in the amplitude of oscillations is not observed.

With an increase in NF (with a change in the tension of the spring (6) – "EE"), the inductive resistance of the coil of the electromagnetic induction sensor (17) increases. This leads to a decrease in the useful signal that is taken from said sensor (17). To eliminate this phenomenon, the sensor (17) is moved towards the permanent magnet (14) (N/S) by reducing the gap between them.

Approaching the sensor (17) to the permanent magnet (14) (N/S) leads to an increase in the amplitude of the signal taken from the sensor (17) and, accordingly, to an increase in the power generated by the LFA.

The system of magnetodynamic agitation of oscillations (MDOA) is designed to disrupt the cyclic oscillations of a dynamic system with its own (self-resonant) frequency.

A feature of the MDOA system is that it does not have direct contact with the moving ferromagnetic armature and the ferromagnetic pads (11) fixed to it, and thus the influence of the excitation system on the NF of the dynamic system (DS) is excluded.

The MDOA system works as follows (Fig. 5). The electromagnetic induction sensor (17), fixed in the cup (16) on the lower cover (2), is in the field of the permanent magnet (14) (N/S). When the oscillations of the "moving anchor" are forced into agitation, an electromotive force (EMF) is induced in the induction sensor (17), due to which the bridge becomes unbalanced, and current begins to flow in the input circuits of the differential amplifiers of the LFA. Moreover, the law of its change corresponds to the law of oscillations of the "moving anchor". Next, the signal is fed to the input of the LFA, in which it is amplified. At the output of the LFA, the signal changes relative to the signal at the LFA input by 180°.

The LFA is designed to convert the signal coming from the induction sensor (17) into an electric current intended for interrogating EM coils (8). The LFA operating mode is selected in such a way that it responds only to an additional half-wave of the signal from the electromagnetic sensor (17). In this way, the moving ferromagnetic anchor (dynamic system as a whole) is loaded with the frequency of its own (self-resonant) oscillations.

The EM (8) block is designed to create an electromagnetic field and transmit its forces to the ferromagnetic pads (11). The EM (8) block, which is fixed on the cover (2), with the help of auxiliary structural elements, namely, the fixing nodes (3), has the ability to move (together with the covers (2)) along the guides of the housing (1) to change the gap between the ferromagnetic pads (11), rigidly fixed on the upper and lower surfaces of the non-magnetic plate (10) of the "moving anchor ", and the indicated electromagnets (8).

The design of the experimental setup provides for the adjustment of the frequency of oscillations and, accordingly, the amplitude of oscillations by changing the gaps between the EM (8) blocks and the ferromagnetic pads (11) of the "moving anchor ".

The dynamic system (DS) is designed to receive the excitation force from the EM (8) blocks and create undamped mechanical oscillations of the "moving anchor" with the CO fixed on it, and in-phase electrical oscillations in the "ID-NF-EM" system, the frequency of which is exactly equal to the NF of the system "the object of control - moving anchor". The peculiarity of the DS is that it does not have direct contact with sources of agitation power – EM (8), the influence of the excitation system on the DS is excluded (lack of influence on the NF).

The principle of operation of the DC is based on the fact that during mechanical oscillations of the movable ferromagnetic armature, which rests symmetrically on elastic elements (the role of which is performed by metal springs 6), the change in the weight of the dynamic system due to the connection of the CO will lead to a proportional change in the NF of the DC.

The use of springs 6, as an elastic element, will allow to change the dynamic response of the DC in the process of compression of the springs 6. Based on this, the formed self-oscillating system will change the NF not only due to the attached weight of the CO by an amount that is proportional to this weight, but also directly proportional to the stiffness of the elastic element (EE) 6 and its static deformation.

Structurally, the DS consists of a "moving anchor" on which ferromagnetic pads (11) in the form of plates are fixed, and EE (6), the role of which is performed by metal springs located symmetrically relative to the non-magnetic plate (10) and having the same characteristics. The characteristics of EE (6) are given in coordinates (w/m). One end of the springs (6) rests against the non-magnetic plate (10) of the "moving anchor", and the other end - against the cover (2), with the help of which (by moving it along the longitudinal axis "LA1" of the body (1)) it is possible to change the amount of their static deformation. At the upper end of the rod (9) of the "moving anchor" is fixed the base – the "plate" (15), to which the CO is attached, and at the lower end of the rod (9) - the permanent magnet (14) (N/S).

On the upper and lower ends of the rod (9) of the "moving anchor" with tension, bronze bushings (13) are planted, which have frictional contact with the fluoroplastic gasket (7), which is placed in the ring (5). It is the combination of such a pair of elements that rub against each other, namely, "bronze – fluoroplastic" gives a minimum coefficient of friction, which gives a minimum error when measuring the NF of DS.

The main link of the DS is elastic elements - metal springs (6), which have constant stiffness.

During DC oscillations, the permanent magnet (14) (N/S), fixed at the lower end of the rod (9) of the "moving anchor", will cyclically approach the sensor (17) (fixed in the body of the cup (16)), in the windings of which a signal will be induced in the form of EMF induction. This signal in the form of EMF induction is amplified in the LFA and is fed to the EM block (8), which, acting on the ferromagnetic pad (11) of the "moving anchor" with an agitating force *P(t)*, promotes the movement of the latter in the direction of action of the agitating force *P(t)* (Fig. 7).

While moving, the "moving anchor" compresses the spring (6). Having reached the equilibrium position, when the agitating force *P(t)* will be equal to the elastic force of the spring (6), the structure ("moving anchor" with the CO placed on the "plate" (15)) will begin to return to the original equilibrium position under the action exerted by the elastic forces of the spring (6). The EMF in the sensor coil (17) changes its sign to the opposite and, after amplification in the LFA, is directed to another EM (8) block. The agitating force *P(t)*, which will originate from this other EM (8) block, will move the "moving anchor" with the CO fixed on the "plate" (15), in the other direction – opposite to the first half-period of oscillations. Non-damping mechanical oscillations of the structure arise with the NF corresponding to the weight of the original DS with the attached CO. The specified oscillations will correspond to the initial value of the NF of the dynamic system (with the attached CO) at an unchanged amount of spring tension (6).

By varying the tension force of springs (6), we obtain the dependence of the NF on the weight of the attached CO (coordinate (w/m)). However, such coordinates will be valid only for COs that have an integrity of structure – are rigid loads.

The presence of any cavities (filled with liquid filler, viscous or loose substance) or moving elements in the CO will lead to a large error in determining the actual NF.

For the removal of this defect it is necessary to boil thoroughly inflexibility descriptions of (6), that on family of curves C_i in coordinates (w/m) to get the law of change C depending on force of tightening of spring 6, id est from the increase of inflexibility of the oscillating system (DS).

By changing the tightening force of the spring (6) with the help of auxiliary structural elements (fixing nodes (3)) by reducing the distance between the upper and lower covers (2), we change the damping properties of EE (6)). Since the DS is a frequency-selective oscillating circuit, it will enter the mode of its own (self-resonant) oscillations again, but with a frequency greater than the previous one, with the same attached CO weight.

By varying the tightening force of the springs (6), it is possible, for the same CO weight (known, used as reference) to obtain a family of curves C_i in coordinates w/m, where m – reference weight; C_i – stiffness EE.

In the process of frequency control measurements, according to the data $w = m$, it is possible to determine the weight of the CO.

If, as a result of the measurements, no dispersion of the NF value is found, this indicates that the CO has no elements capable of damping oscillations (i.e. there are no cavities with a liquid filler, viscous or loose substance, internal cantilever-fixed nodes (which can oscillate relative to places of attachment) or elements that can move when the position of the CO relative to the static one changes).

Thus, the experimental setup ensures the inclusion of the CO (its weight) in the self-oscillating system. In this system, a movable ferromagnetic anchor (with the CO attached), resting on elastic elements, plays the role of a resonant high-Q circuit. At the same time, there is no need for elements that require manual adjustment, and the accuracy of measuring such a dynamic characteristic as NF is significantly increased.

The NF parameters are recorded by the Ч3-32 (CHZ-32) type EFC, the information from which is fed (when used on board of a space station) to a computer for conversion into weight dimensions and display of control results on peripheral devices.

Conclusions

Thus, an experimental unit was created and proposed for determining the body weight of astronauts and the low weight of objects in zero gravity.

NF was chosen as a diagnostic parameter for high-precision determination of the weight of CO in zero gravity.

The weight of the CO is determined by changing the NF of the dynamic system "object of control - moving anchor" depending on the attached weight of the CO.

The general view of the experimental unit and its structural diagram are presented.

The structural and compositional diagram and the block diagram of the experimental unit are presented.

The peculiarities of the operation of the MDOA and DS system are explained.

The experimental unit allows you to determine the weight of the CO and its condition (heterogeneity, presence of liquid filler, oscillating parts, etc.). The installation can be used both on orbital space stations and on Earth.

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Експериментальна установка для визначення ваги тіла космонавта та малої ваги об’єктів в умовах невагомості

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Анотація. Перехід космонавта у невагомість призводить до певної перебудови організму, у тому числі до перерозподілу у ньому потоків рідини. Стимулюється процес обезводнення організму, космонавт втрачає у вазі. Знання закономірностей змін ваги тіла космонавта, збереження її в нормальних межах завдяки раціональному, розподілу навантаження, відпочинку, фізичних вправ, продуманому режиму харчування украй необхідно, щоб забезпечити космонавту найбільш сприятливі умови для адаптації у невагомості, а також краще підготувати його до повернення на Землю. Повернення з космічної станції на Землю матеріалів наукових досліджень і експериментів, а також обладнання також потребує високоточного визначення малої ваги об'єктів. **Об'єктом дослідження** є експериментальна установка, що дозволяє вимірювати вагу (параметри) тіла космонавта і малу вагу об'єктів (обладнання, пристроїв тощо), що коливаються. **Предметом дослідження** є частота власних коливань динамічної системи. **Метою наукової роботи** є розробка експериментальної установки для визначення ваги тіла космонавта та малої ваги об’єктів в умовах невагомості. **Висновки.** Запропоновано експериментальну установку для визначення ваги тіла космонавтів (астронавтів) та малої ваги об'єктів (об'єктів контролю (ОК)) в умовах невагомості. Для високоточного визначення ваги ОК в умовах невагомості у якості діагностичного параметра обрана частота власних коливань (ЧВК). В експериментальній установці визначення ваги ОК здійснюється за зміною ЧВК динамічної системи «об'єкт контролю – рухомий якір» залежно від приєднаної ваги ОК. Розкрито сутність роботи експериментальної установки та представлено її загальний вигляд і структурна схема.

Ключові слова: невагомість; вага тіла космонавта; мала вага об'єктів; об'єкт контролю, експериментальна установка; частота власних коливань; динамічна система.