INSTITUTE FOR SPACE RESEARCH
ACADEMY OF SCIENCES OF THE USSR

EQUIPMENT FOR STUDY OF SECONDARY ELECTRON HF DISCHARGE ONBOARD COSMIC STATION "SALYUT" CONDUCT OF THE EXPERIMENT AND ITS RESULTS

K.I.Gringauz, V.I.Patsaev, V.A.Rudakov,
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Presented to XXIV International
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Moscow 1973

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1. Introduction

The study of the high-frequency secondary electron resonance discharge was performed by V.I.Patzaev on the orbital station "Salyut" in June, 1971.

The HF-secondary electron resonance discharge is the physical process in which an oscillating space charge exists in the HF-electric field between electrodes due to a secondary electron emission from the surface of electrodes [1,2] . In the literature this process is also named "the secondary electron resonance breakdown", "the multipactor discharge", in this paper the term "resonance discharge" is used for brevity.

An avalanche-type resonance discharge can arise in a vacuum when electrons happen to penetrate into the space between electrodes. This phenomen was discovered in the 1940 in vacuum devices such as klystrons and charged particle accelerators. Main characteristics of the resonance discharge have been found out for plane electrodes in a vacuum [1-4] .

One can describe the phenomenon in the following simplified way. If the HF-voltage is applied to plane electrodes in a vacuum (the mean free path of electrons is much longer than the distance between electrodes) then electrons between electrodes can gain the energy sufficient to create the secondary emission from the electrode surface. The process breaks into an avalanche under certain conditions for the frequency and the amplitude of the HF-voltage and the distance between electrodes. As a result the electron density between electrodes becomes considerable. A detailed consideration of the resonance discharge mechanism is very complicated.

It should be noted that the HF-voltage at which the discharge arises (the critical voltage) depends on the electrode material, the state of the electrode surface and on the discharge duration. A voltage applied to electrodes simultaneously with the HF-voltage also affects the character of the discharge. In a vacuum it was possible to supress the resonance discharge by means of increasing the dc voltage.

The results of laboratory investigations gave grounds to suggest that the resonance discharge can arise in systems with complicated configuration of electrodes, in particular on spacecraft aerials and that free electrons of medium must also affect the character of the discharge. One can expext that in this case the HF-power lesses increase and characteristics of aerial systems worsen. However, the impossibility of an adequate simulation of space condition and spacecraft motion effects in ground based vacuum chambers did no allow to make definite conclusions of the existence of such a process in case of the real flight in the space.

The purpose of the investigation described in the present paper was an experimental detection and study of the resonance discharge during the flight of the spacecraft in the ionosphere and simultaneous measurement of the charged particle density. The measurement of the local charged particle density in the ionosphere along the spacecraft orbit, which is necessary for more complete understanding of results of the resonance discharge investigation is also interesting by itself.

If such investigations were performed on the unmanned spacecraft then because of lack of the knowledge of the phenomenon parameters it would be necessary to use highly complicated automatic equipment. The possibility for the cosmonaut to take part manually in the experiment allowed to develop and to use the equipment and the experiment program which implied an active participation of the investigator in measurements. The apparatus made it possible to charnge the regime of the experiment and to maintain a visual observations of some physical characteristics. The cosmonaut could change condition of the experiment depending on observed results.

The main purpose of the first of measurements was to detect the resonance discharge and to reveal conditions of its existence. On the orbital station "Salyut" measurements were made by the cosmonaut V.I.Patsaev who succesfully performed the first study of the resonance discharge in the ionosphere during the flight.

2. Measurements technique and apparatus

2.1. The resonance discharge study. The resonance discharge was studied for electrodes of three types. Shapes of the electrodes were similar to that of aerials used on spacecrafts. All electrodes with respect to dc voltage were isolated from the station body.

At each given moment one of electrodes was used to which the smoothly variable pulsing high-frequency voltage and the dc voltage with the stepwise control were applied.

First of all it was necessary to register the fact of the rise of the discharge. For this purpose the meter of the high-frequency discharge current was used which detected an increase of the medium conductivity in the space between electrodes in case of the discharge. It was necessary to have the possibility to change the high-frequency power and the dc voltage applied to electrodes in order to understand their influence on the rise and the character of the resonance discharge. The HF-probe-receiver with two small aerials (the loop and the symmetrical vibrator) mounted on a boom which could displace near electrodes was used to measure the distribution of the HF-field near electrodes.

2.2. The measurement of the charged particle local density. In the mentioned experiments the positive ion density was measured by means of ion traps [5] . As the ionosphere is electrically neutral and negative ions are practically absent at the altitude of the station "Salyut" flight, measurements of the ion density n_i give us values of the electron density n_e

On the station "Salyut" three spherical ion traps were mounted. Two of them were fixed and were intented to measurements in undisturbed medium, the third trap was mounted on the moveable boom near receiving aerials (only two traps could simultaneously operate). Results obtained by means of spherical traps are almost independent on the trap orientation with respect to the Sun and the velocity vector of the incoming particle flux (until the trap enters the spacecraft ion shadow). The inside electrode of the trap, the collector, was at a negative constant potential. The potential of the outside electrode, the grid, was controlled by the experimentator. When the grid potential varied according to the saw-tooth law the volt-ampere characteristics of the collector current allowed to determine the density n_i .

2.3. Some information about apparatus. Each of three electrode systems in which the discharge was observed could be connected to the controlled attenuator (0-13 db) regulating the level of the HF-power from the pulse generator (the pulse power P=300 w. the carrier frequency is about 180 MHz, the pulse duration is 3 μsec) by means of the special high-frequency switch. The attenuator unit contained sensors of the incident and reflected power.

All measured parameters were recorded on the photographic film by means of a small loop oscillograph. The photographic films were processes on the Earth after returning of the spacecraft. The cosmonaut also made records in the flight log-book.

The study program of a cosmonaut in the experiment was drawn up as a part of the flight log-book. All basic operations were enumerated and the space for fixing of results of measurements, observed effects and remarks was alloted.

At first the description of the operational sequence was very detailed. However, in the course of the cosmonaut training it become clear that the detailed instruction for repeated operations was not required. So the program was revised with the participation of V.I.Patsaev. In the final variant only the purpose of some group of operations was indicated (for example, "recording") and at the end of the program such standard operations were decoded in detail. Tables for results of observations in the flight log-book were also simplified.

All instrument control and the indication of measured parameters were concentrated in one device the control unit. By means of this unit the cosmonaut performed the experiment following its course. In Fig.1 the general view of the control unit is given.

In the control unit, in particular, there were relay circuits of the control of the HF-power attenuator drive, the movable boom drive, the control of electrode HF-switches, the control of different regimes of the recording. The state of controlled assemblies was checked by light indicators (red and green light diodes were used).

All measured currents and voltages were amplified by special amplifiers before setting the loop oscillograph or a pointer-type instruments. These amplifiers were also in the control unit. In the same unit there was the measuring receiver with the unput stepwise attenuator. The probe current amplifiers allowed to measure currents over the range 10^{-10}-10^{-5}a separated into several subranges. Values of all measured parameters could be visually observed on three pointer-type instruments, which could be switched on into different circuits on desire of the experimentator. Ion trap probe characteristics could be observed on the screen of the electron-beam tube. The photograph of the ion trap (the diameter is 10 cm) is presented in Fig.2.

The experimenter colud choose the optimal regime of the amplification in accordance with the form of the volt-ampere characteristics visible on the screen. The inclination angle of the movable boom was recorded by means of the pointer-type instrument connected to the potentiometric detector.

In spite of a great number of instruments on the front panel (7 pointer-type instruments, the electron-beam tube, 16 switches, 7 buttons, 19 cut-out, 6 regulators, 11 light indicators, 2 film counters) the operation with this panel did not cause serious difficulties. In recordings made by V.I.Patzaev onboard the station "Salyut" there are no remarks about difficulties in the instrument operation.

3. Measurement results

A number of experiments was performed by the cosmonaut V.I.Patzaev by means of mentioned apparatus aboard the station "Salyut" from 16 to 27 June, 1971. Flight-log recording by V.I.Patzaev and oscillographic films recovered to the Earth allowed to reconstruct the course of experiments. V.I.Patzaev conducted eight sets of measurements with the duration from 15 to 90 min. During mentioned experiments the mechanical system of the loop oscillograph was switched on 202 times, every recording covered from one to several tens of measurement cycles. V.I.Patzaev corrected the measurement programme planned on the Earth depending on the real situation. Some experiments were made during his rest time and this is an evidence of his interest in the conducted study.

On the map (Fig.3) are shown projections of the station "Salyut" passes, on which the measurements were condected. Measuring intervals are marked by double thin lines, the sing ◑ indicates the terminator, the arrows indicate the direction of the flight.

All measurements were made at the station rotating around the Y axis directed to the Sun (perpendicular to the longitudinal, i.e., main station axis) with the angular velocity about 3 deg/sec. High-frequency electrodes and ion traps were always shadowed from the direct solar rays by the station body therefore there was no photoemission from electrodes of traps.

One of fundamental results of experiments is the first detection of the resonance discharge on the electrodes mounted on the spacecraft surface during the station flight in the ionosphere. In Fig.4 one oscillograms by V.I.Patsaev is reproduced in which the process the resonance discharge rise was fixed. The following parameters were recorded on the oscillogram: the discharge current (curve 1), the dc electrode voltage equal to +3.5 v (curve 2), values of the power of incident and reflected waves (curves 3 and 4 respectively) one second time marks 5. The decrease of levels on the oscillogram corresponds to the increase of these values. As the high-frequency voltage increases (with the growth of incident and reflected powers) the discharge current arises and increases and its level exceeds the limit of the recording range. Values of incident and reflected powers were recorded in different scales and recordings were shifted each to another by 2 mm in the horisontal direction. The repeating rise of the high-frequency secondary electron resonance discharge is clearly seen in the oscillogram of Fig.4.

When the station rotates around the Y axis the orientation of different parts of its surface with respect to the velocity vector (the direction of the incoming flux of the ionospheric plasma) continuously varies and HF-electrodes can enter the gasodynamical shadow of the station. The influence of this shadowing was revealed in the set of twenty measurements with the interval of 1 min. Every measurement consisted of three cycles of HF-power variations, the duration of one cycle was 2 sec. In intervals between measurements the minimum value of the power was used at which the discharge was absent. Measurements were performed on the day part of the orbit. Values of the critical power and the discharge current proved to be variable depending on variations of the station position with respect to the vector of the incoming plasma flux. Temporal variations of maximum values of the discharge current (opened circles) and values of the critical power (crosses) are given in Fig.5 in relative scale. In the same graph the solid sinusoidal lines periods are equal to the station rotation period. The influence of this rotation on the discharge current is clearly revealed.

It should be noted that the resonance discharge was recorded only in one of three electrode systems.

Positive ion density measurements were made on different parts of the orbit. The experimenter had to choose the optimal regime of measurements in accordance with the form of the volt-ampere characteristics visible on the screen of the electron-beam tube.

The analysis of recordings showed that probe amplifiers of the control unit operated not quite well (V.I.Patsaev could not see ant irregularities in the amplifiers operation, they were revealed only on recordings). Nevertheless, on some parts of the orbit v-a characteristics were obtained which could be decoded. Such recordings were made, for instance, on June 16, 1971 on the part of the orbit 3000 km long. Measurements began near the terminator, shortly before the entering of the station into the shadow. The altitude of the flight was 250 km, the latitude varied from 42° to 50°S. Obtained data are given in Table I)distances with the sign minus correspond to the orbit part illuminated by the Sun).

Not only the obtained data but also the fact of successful ionospheric measurements by means of the instrument controlled by thr cosmonaut is of interest.

There are no remarks of difficulties of measurements in the flight log-book. So the efficincy of the device was tested and it allowed to measure the ion concentration under difficult conditions which cal arise during the study of the resonance discharge. The range of measured concentration values n_i and potentials of trap electrodes could be charged as required.

Conclusion

In present paper the experimental study of the high-frequency secondary electron resonance discharge in the ionosphere is described, basic characteristics of the used apparatus and some obtained data are given.

Main results are following:

1. The high-frequency secondary electron resonance discharge was detected on electrodes near the surface of the orbital station flying in the ionosphere.

2. The high-frequency discharge current and the power at which the discharge arises depend on the station orientation with respect to the velocity vector and change when the station passes from the night part of the orbit to the day one.

The size of the present paper allowed to give only a part of the obteined data. So the influence of the constant potential of electrodes on the discharge, the dependence of the discharge peculiarities on its duration, the influence of the discharge on the electrode impedance are not described.

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FIGURE CAPTIONS

Fig. 1. The general view of the control unit.

Fig. 2. The spherical ion trap (the diameter is 10 cm) installed onboard the station "Salyut".

Fig. 3. Projections of the station "Salyut" passes, on which the study of the resonance discharge was conducted are marked by double thin lines, the sign ◑ indicates the terminator (the boundary between the light and the shadow), the arrows indicate the direction of the flight.

Fig. 4. The oscillograms of the registration of the resonance discharge rise made on June 25, 1971, 23.30 Moscow time.

1 - the discharge current,

2 - dc voltage to the electrode,

3 and 4 - the incident and reflected wave power respectively,

5 - one second time marks.

Fig. 5. Maximum values of the discharge current (opened circles) and critical power values (crosses) measured once every 1 min on June, 26, 1971, 11.35 Moscow time. In vertical direction the scale are relative. The solid sinusoidal lines period corresponds to the station rotation period.

Table 1

Distance from terminator, km	Ion Density n_i, $10^5 cm^{-3}$
-500	1,6
-25	1,8; 1,55
250	1,55; 1,55
500	1,45; 1,35; 1,35
750	1,35; 1,35
1000	1,25; 1,2; 1,25; 1,2
1250	1,25; 1,35
1500	0,85; 1,00; 0,85
1750	0,85
2000	0,85
2250	0,85; 0,75; 0,85
2500	0,85; 0,85

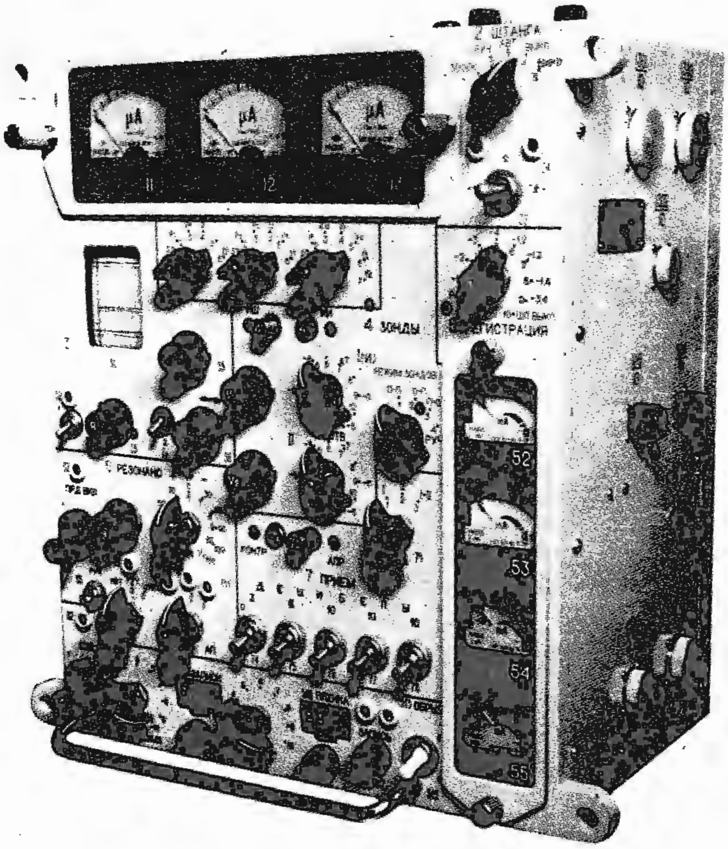


Рис. 1

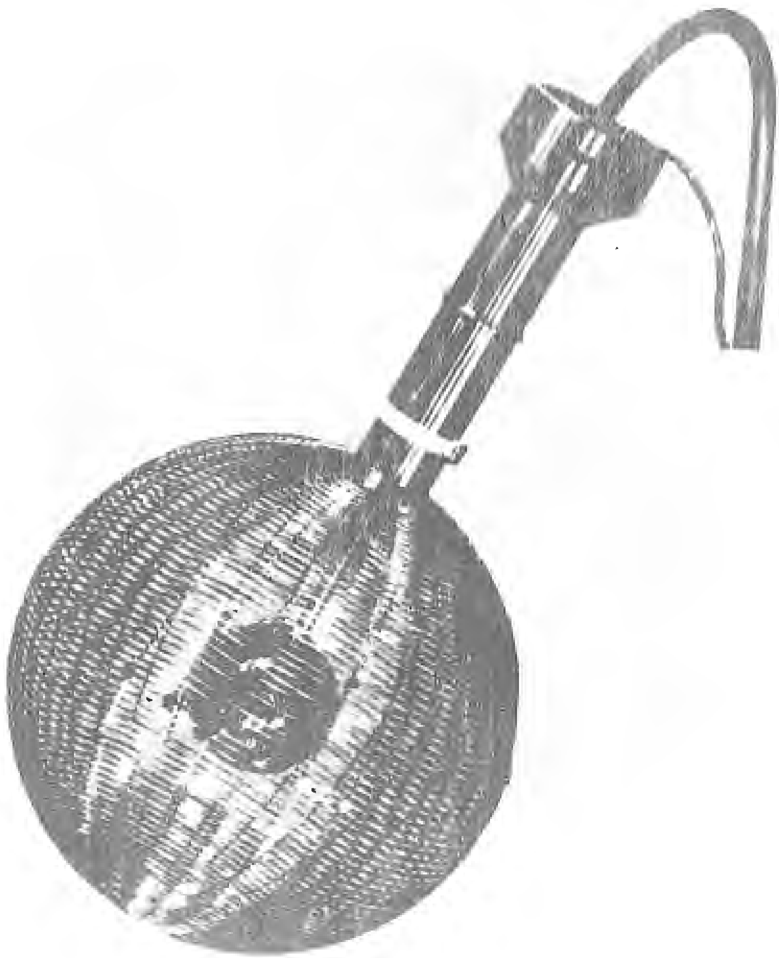
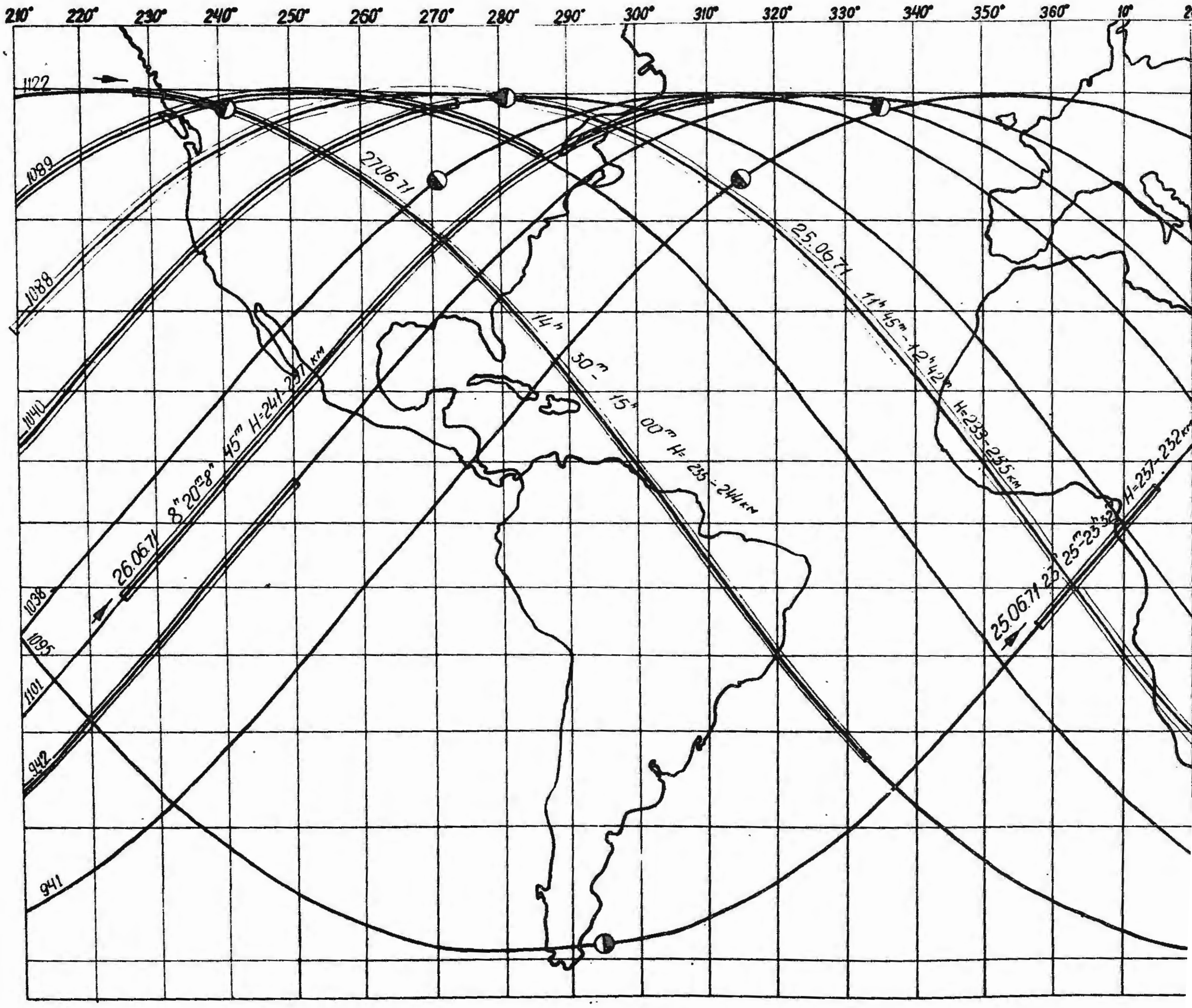


Fig 2


210°
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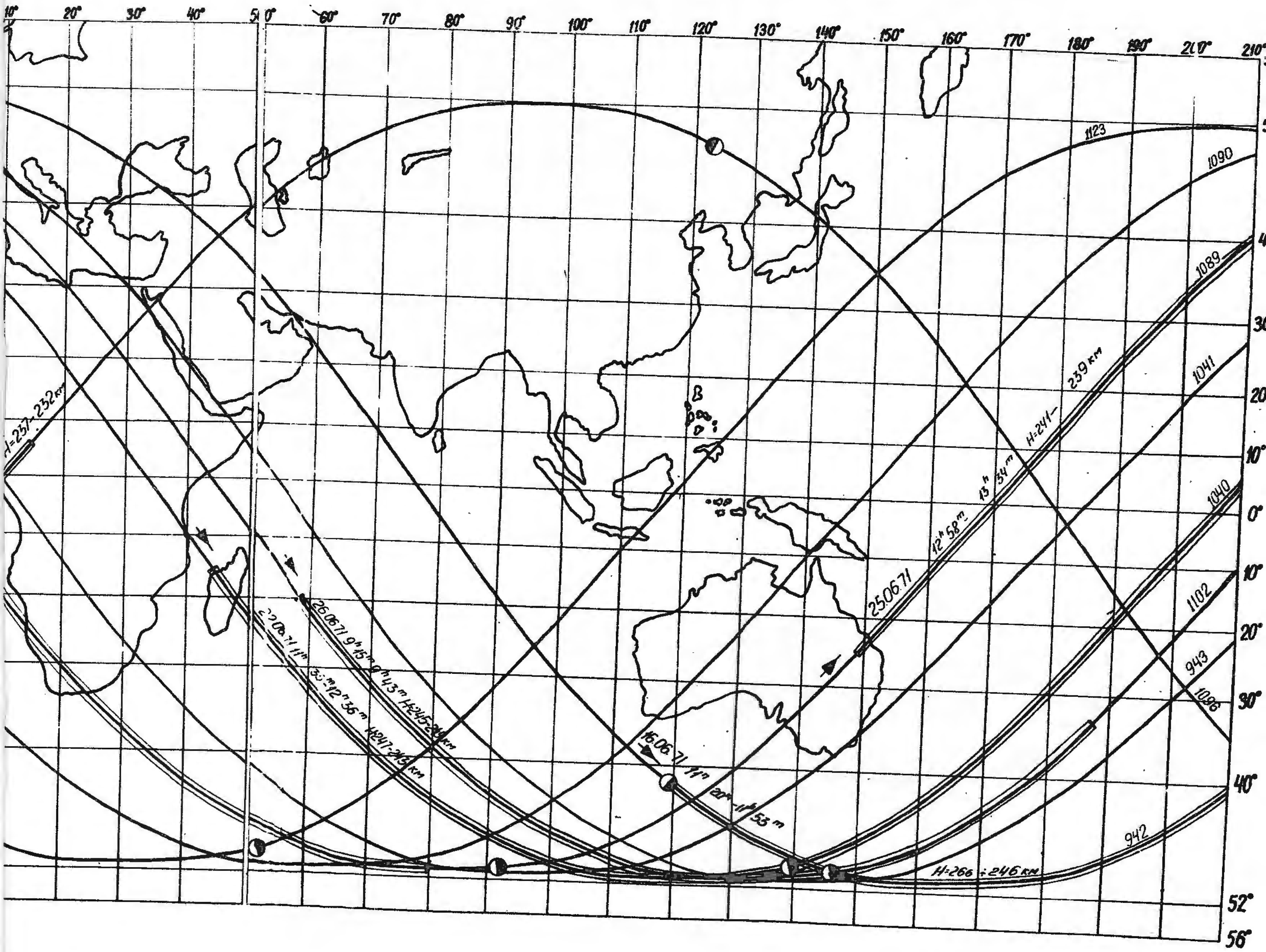
H=233-255 км
25.06.71



10°
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130°
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180°
190°
210°
1123
1090
1089
1041
1040
1102
943
1036
942
H=257-232 км
H=241-239 км
12h58m 13h34m
25.06.71
26.06.71 9h15m 9h43m H=245-244 км
16.06.71 11h 20m-11h53m
H=266-246 км
10°
0°
10°
20°
30°
40°
52°
56°

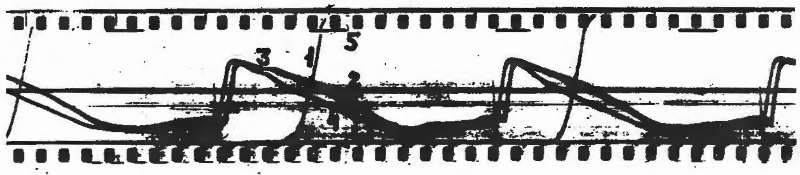
3
1
5
2

Fig. 4

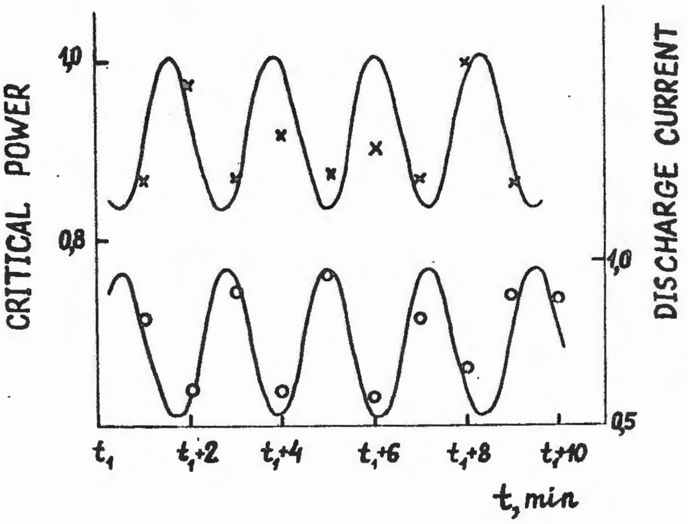
CRITICAL POWER
DISCHARGE CURRENT
1,0
0,8
1,0
0,5
t1
t1+2
t1+4
t1+6
t1+8
t1+10
t, min

Fig.5