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STARTING-UP THE IRBENE 16-m FULLY STEERABLE PARABOLIC ANTENNA FOR RADIOASTRONOMIC OBSERVATIONS

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The prospects of the Engineering Research Institute of the Ventspils International Radio Astronomy Center (VIRAC) for the future development are associated with modernization of the radio-telescope RT-16. Its 16-m fully steerable mirror antenna is a second of the kind located in the VIRAC territory. As a result of renovation of its infrastructure, the reliability of electric power supply has been improved, with the access established to the high-speed data transfer link of the Geant network through a 30 km optical communication cable. The gear ratio of the antenna's azimuthal rotation controller for the high-speed electric motor is ~ 850, and for the low-speed one it is ~ 54400. To control the azimuthal and elevation antenna's movement, a cabling scheme of the power supply and electric motors was devised. An experimental scheme for studying the operation of the antenna's drive was developed using static voltage converters (Simoreg DC-Master 6RA70) to power the 2.6 kW DC electric motors. The maximum power consumed by the positioning system to rotate the antenna in azimuth at the motor's rotational speed of 1000 rpm is 600–800 W. The low-speed motor of the drive can provide azimuthal rotation of the antenna at a speed of 14.76 °/min.

Key words: *VIRAC, radio-telescope RT-16, radio-astronomy, radio-interferometry, motor control, DC converters, renovation of the control system.*

1. INTRODUCTION

At the present time, the Engineering Research Institute "Ventspils International Radio Astronomy Center" (ERI VIRAC) at Irbene employs the operating 32-m radiotelescope (RT-32). The Latvian scientists, in collaboration with partners from the European Very Long Baseline Interferometry Network (EVN) in Europe and Russia, are actively taking part in the radio-astronomic observation sessions on scanning the Sun, as well as identifying and finding out the precise orbits of objects in space [1, 2]. The immense preparatory work allowed carrying out the investigations during which the drive unit control system was rebuilt, radio-reception equipment installed, and the ERI VIRAC's infrastructure renovated.

With financial support from the European Regional Development Fund (ERDF), the project of replacing the old electric network by a new 20 kV one had been worked out, according to which the reliability of electricity supply was improved; in particular, it is now possible to switch operatively the power supply from one of two independent electrical transmission lines through three 250 kVA transformers.

The second important result of the infrastructural renovation is a 30-km long optical communication line made up of 16 fibres. From one end the optical fibre network connects all the objects located in the ERI VIRAC territory, while from the other this fibre line is connected to the Ventspils University College and has the access to a high-speed data transfer link with the Geant network.

2. DESCRIPTION OF THE ERI VIRAC INFRASTRUCTURE

The new possibilities and prospects of ERI VIRAC's development are associated with modernization of the radio-telescope RT-16 with a 16-m fully steerable mirror antenna − the second antenna located in its territory.

Built in 1964, the Ground Station (GS) operated until 1990 in the radio-reception mode, being adjusted for registration of signals from the objects in near-earth orbits, after which its maintenance was stopped. In 1993, the GS receiving equipment was demounted, the drive control system damaged and brought to an unusable state.

In 1999, the ERI VIRAC's specialists made a first examination of the drive's technical condition, and an attempt was made to restore the station's ability to work using the repaired motors [3, 4].

In 2008, work on modernization of the RT-16 buildings and renovation of the ERI VIRAC infrastructure was started. In 2009, at the first stage of modernization a second floor was built on the annex surrounding the bearing structure of the antenna (Fig. 1) and the infrastructural renovation was completed.

Fig. 1. Radio-telescope RT-16 with a fully steerable antenna.

The station has a deep well, purification works, an autonomous gas-fired heating system (Junkers), and gas boilers (given as a gift by the Robert Bosch Ltd.

Co). The electricity supply is provided by a 250 kVA transformer through a 980-m long line consisting of two aluminium cables with a $4{\cdot}120\ mm^2$ section. The working premises in the annex are connected to the ERI VIRAC computer and the telephone network.

Figure 2 shows schematically the relative position of radioastronomy-related objects − the radio-telescopes RT-16, RT-32 and the GPS laboratory − in the territory of ERI VIRAC. On the scheme the geographical coordinates in the WGS-84 system are shown with an accuracy of ±1″.

The improved infrastructure and the complex of fully steerable 16-m and 32-m parabolic antennas will allow solving in the future a wide range of scientific problems in the field of astronomy as well as filling the commercial orders for servicing satellites and deep-space vehicles.

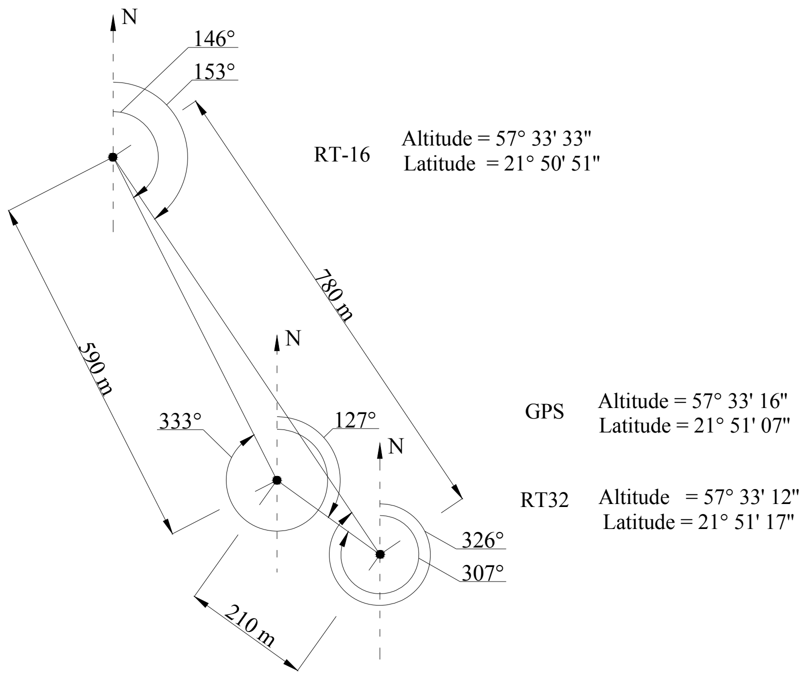

Fig. 2. The disposition and geographical coordinates of VIRAC's radioastronomy-related objects in the WGS-84 system (accuracy ± 1″).

Since 2009 the Ventspils University College has been implementing the ESF's Attraction of Human Resources to Science, project Nr. 2009/0231/1DP/ 1.1.1.2.0/09/APIA/VIAA/151. Specialists from the fields of radio-astronomy, electronics, mechanics, and information technologies are involved in the execution of the project "Technologies for receiving, transmitting and processing the signals related to artificial Earth satellites".

The objectives of the project are as follows.

1. To update the mechanical systems of the radio-telescopes and the most important software in compliance with the international requirements.

2. To provide remote and automated control over positioning the radio-telescope antennas.
3. To considerably increase the safety of the RT-16 and RT-32 construction, to improve the surface quality of their main mirrors; to raise the transfer speed of the antennas to 1°/s, and the positioning accuracy − to 5 arcs.
4. To improve the energy efficiency of the drive systems of radio-telescopes; to create an opportunity to simultaneously run the radio-telescopes RT-32 and RT-16 in a local 2-antenna interferometry mode.

To achieve the chosen objectives, it is necessary to collect bulk of information about the current condition of RT-16 and to identify all the equipment whose functionality substantially affects the performance of the whole antenna complex.

For assessment of the technical condition of the antennas' construction the experience of specialists from the Special Design Bureau of the Moscow Power Engineering Institute was used; they also took part in designing and building work.

Based on the results of diagnostics, it is envisaged to formulate technical tasks for the antenna modernization, to work out a technical project, and to perform the necessary improvements, adjustment and testing. The resultant scientific tool will be employed for radio-astronomic observations.

Apart from that, during modernization it is planned to create a permanently functioning system which would control mechanical deformations of the most important components at the antenna's normal operation or under the influence of environmental factors.

3. CHECK ON THE TECHNICAL STATE OF THE DRIVE FOR ANTENNA AZIMUTHAL ROTATION

The RT-16 receiving antenna refers to a precise device of the mirror telescope class TNA-110 (according to the manufacturer's classification) [5]. Preparation of the mentioned radio-telescope to modernization was difficult to perform since the ERI VIRAC's experts had no original technical documentation for the antenna positioning system and the drive unit. Accordingly, in order to develop technical specifications for this purpose, it was necessary to investigate the wiring and the main technical characteristics of the radio-telescope equipment.

Figure 3 shows schematically the arrangement of the frame aerials and ground equipment inside a reinforced concrete tower (full height 32.5 m). The basement (position 3 on the scheme) is connected with the radio-telescope RT-32 through the underground tunnel.

Figure 4 shows the positioning system in A–A cross-section.

Figure 5 displays the connecting point of the azimuthal axle and the fixed base platform with foundation. In this figure, position 9 shows ball bearings which contain 72 balls interconnected by a cage of 6 pieces in a single container. Position 11 indicates two of the three pins through which the antenna and the whole slew system rely on the reinforced concrete foundation.

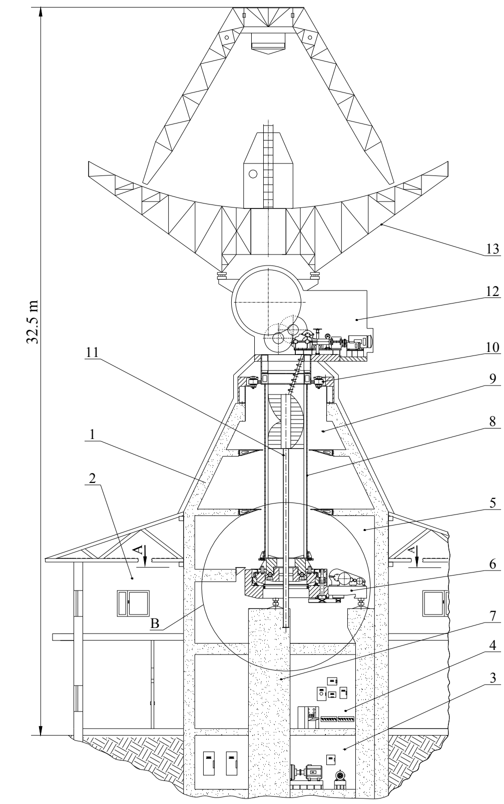

Fig. 3. Arrangement of the antenna frame and positioning system of RT-16 radio-telescope. *1* – 6-storey reinforced concrete supporting structure; *2* – 2-storey circular extension; *3* – 1^{st} floor: basement for DC converters and switchgear cabinets; *4* – 2^{nd} floor: stand control panels and switchboards with circuit breakers for three-phase voltage commutation; *5* – 3^{rd}-4^{th} floors: thrust bearing and azimuthal rotation drive unit; *6* – fixed support platform; *7* − reinforced support legs; *8* − vertical column axle of azimuthal rotation; *9* − 6^{th} floor: measuring equipment of azimuthal rotation; *10* − upper roller bearing for axial rotation; *11* – protective casing of the azimuthal measuring axle; *12* − rotating cabin with the elevation drive unit; *13* – antenna frame.

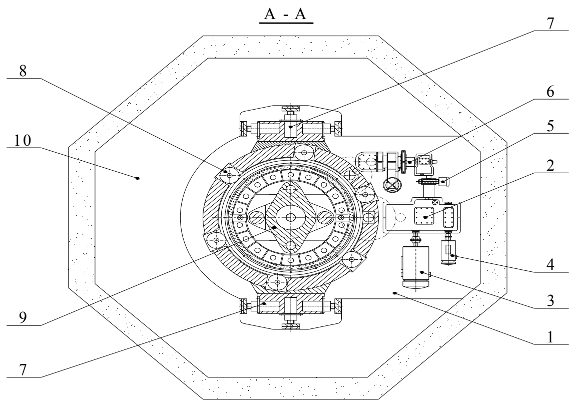

Fig. 4. Arrangement of side rollers in the azimuthal axle lower bearing and the azimuthal rotation drive. *1* - fixed support platform; *2* - the gear reducer; *3, 4* - fast and slow rotation DC motors; *5* - electromagnetic brake; *6* - backlash compensation mechanism; *7* - assembly-adjusting hydraulic jacks; *8* - side rollers of the azimuth axis lower bearing; *9* - crossing joint of the vertical axle column (azimuthal rotation) and a fixed base platform; *10* - intermediate reinforced concrete floors.

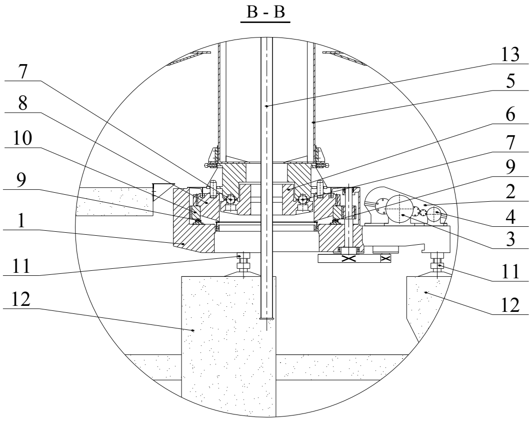

Fig. 5. Azimuthal axle and the fixed base platform with foundation.
1 - fixed support platform; *2* - the gear reducer; *3, 4* - DC motors for fast and slow rotation of the antenna; *5* - vertical column axle (azimuthal rotation); *6* - vertical column support cross-bar (azimuthal rotation); *7* - spherical support; *8* - support bearing carriage; *9* - ball bearings; *10* - ring gear; *11* – support pins ; *12* – stands; *13* - protective casing of the azimuthal measuring axle.

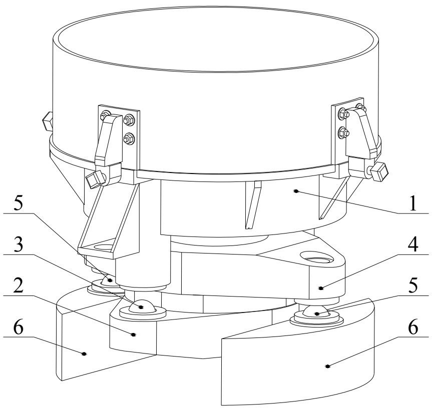

Fig. 6. Arrangement of the ball joints.
1 – vertical column axis of azimuthal rotation; *2* – lower arm crosses; *3, 5* − balls of spherical support; *4* − upper arms; *6* − bearing support carriage.

Figure 6 demonstrates the designed position of the ball joints on the shoulders of the cross and their connections with the azimuthal axis and carriage support bearing. Each of the four balls in the spherical support is 160 mm in diameter.

Figure 7 shows the kinematical coupling of the fast- and slow-rotation motors of the drive (DC2 and DC3, respectively), with gearwheel Z32 connected to the azimuthal rotation axis. Differential gears Z1-Z18 and Z33-Z35 are operated by one of the DC motors (DC2 or DC3) with a corresponding electromagnetic clutch (C1 or C2). Gears Z19 - Z31 of the backlash compensation mechanism are operating only in the case of motor DC3 rotation.

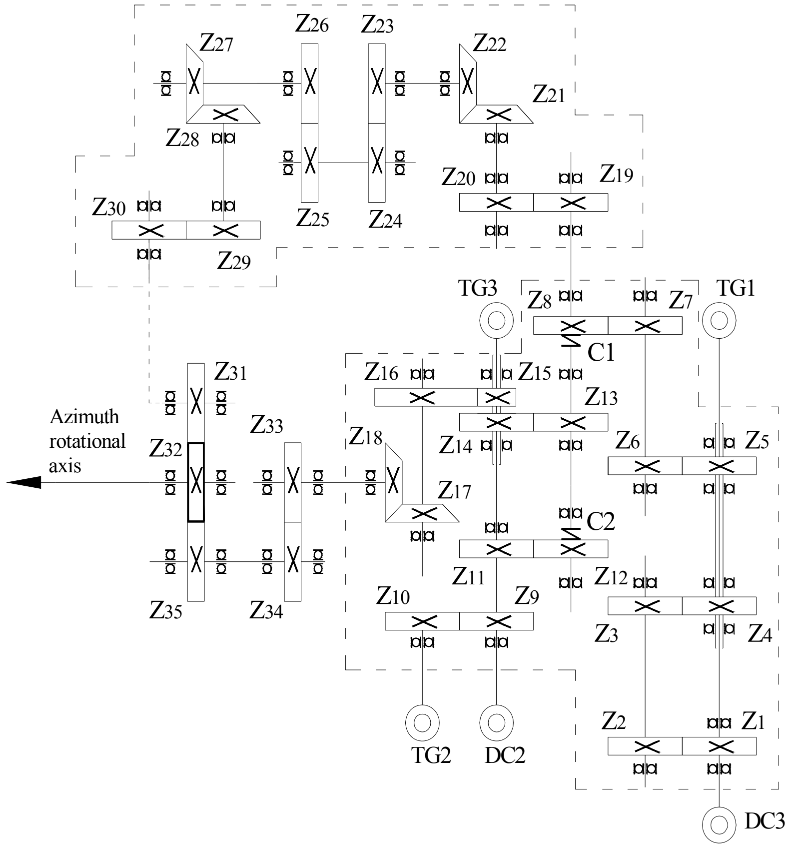

Fig. 7. The gear backlash compensation mechanisms with the antenna drive motors for fast and slow azimuthal rotation. DC2, DC3 – fast and slow rotation motors; Z32 – gearwheel; Z1–Z18, Z33–Z35 – differential gears; C1, C2 – electromagnetic clutches; Z19–Z31 – backlash compensation gears.

The output shafts of electric motors and DC2, DC3 are coupled to tachogenerators TG1-TG3. The output shafts of the tachogenerators and the related motors rotate with the same speed.

The technical parameters of motors DC2, DC3 for the azimuthal rotation drive units and of motors DC6, DC7 for the elevation drive units are given in Table 1.

The kinematic diagram of Fig. 7 contains 6 bevel gears, 22 cylindrical gears with bevelled teeth and 7 cylindrical gears with straight teeth. The size and number of gear teeth are indicated in Tables 2 and 3.

The gear ratio of the fast-rotation motor is calculated as

$$N_{az.fast} = \frac{n_{\mathrm{DC2}}}{n_{az.}} = 850\,, \tag{1}$$

and of the slow-rotation motor (from the side) as

$$N_{az.slow} = \frac{n_{\mathrm{DC3}}}{n_{az.}} = 54400\,, \tag{2}$$

where n_{az} is the rotational speed of azimuthal axis,

n_{DC2}, n_{DC3} is the rotational speed of the fast (DC2) and slow (DC3) motor, respectively.

Table 1

Technical parameters of DC drive motors

Nr.	Parameter	DC3, DC7	DC2, DC6
1	Model	DPM-12	DPM-52
2	Rated power, kW	2.6	49.0
3	Rated voltage, V	220	220
4	Rated current, A	13.5	250
5	Rated speed, rpm	1180	970
6	Maximum speed, rpm	3300	2100
7	Rated field voltage, V	220	220
8	Field winding resistance, Ohm	270	–
9	Rated brake voltage, V	220	220
10	Brake winding resistance, Ohm	130	–

Table 2

Basic dimensions of the gears in the differential azimuthal drive unit

Gear type	Label in drawing	Gear tooth step – t, mm	Gear tooth count (z)	Diameter of the quotient circumferences, Dd, mm	Outer diameter, De, mm	Internal diameter, Di, mm
Cylindrical with bevelled teeth	Z1	10	26	83	89	71
	Z2	10	104	331	338	265
	Z3	10	26	83	89	71
	Z4	10	104	331	338	265
	Z5	10	65	207	213	168
	Z6	10	65	207	213	168
	Z7	10	27	86	92	73
	Z8	10	108	344	350	275
	Z11	13	62	257	265	222
	Z12	13	62	257	265	222
	Z13	13	28	116	124	105
	Z14	13	80	331	339	283
	Z15	17	23	125	135	119
	Z16	17	99	536	547	477
	Z9	5	108	172	175	99
	Z10	5	108	172	175	99
Bevel	Z17	36	51			
	Z18	36	51			

Table 3

Basic dimensions of the gears in the backlash compensation mechanism of the azimuthal drive unit

Gear type	Label in drawing	Gear tooth step, t, mm	Gear tooth count (z)	Diameter of the quotient circumfer-ences, Dd, mm	External diameter D_e, mm	Internal diameter D_i, mm
Cylindrical with be-velled teeth	Z19	8	28	71	76	57
	Z20	8	70	178	183	134
Bevel	Z21		35			
	Z22		35			
Cylindrical with bevelled teeth	Z23	15	26	124	134	116
	Z24	15	78	373	382	328
	Z25	19	26	157	169	151
	Z26	19	52	315	327	290
Bevel	Z27		50			
	Z28		50			
Cylindrical with straight teeth	Z29	22.5	26	186	201	182
	Z30	22.5	130	932	946	855
	Z31	52	18	298	331	319
	Z32	52	202	3345	3378	3237
	Z33	29	19	175	194	181
	Z34	29	133	1228	1247	1154
	Z35	52	18	298	331	319

Originally, starting and monitoring the operation of the drive unit devices was carried out from the remote control desk shown in Fig. 8.

Fig. 8. The control panel (originally used to operate the antenna manually).

Originally, it was possible for the control panel operator to drive the antenna and to monitor its movements on a goniometric indicator coupled to selsyns. Placed on the console backside were: the connector clamps for cables, operating terminator switches, triggering circuits of magnetic starters, contactors, and measuring devices.

Figure 9 shows a cabling diagram of the antenna drive related devices. The switch systems of power supplies, drive motors and wiring used for the antenna azimuthal and elevation movement control unit were identical, so the devices related to the azimuthal rotation of the drive have index 1, while those related to the elevation − index 2.

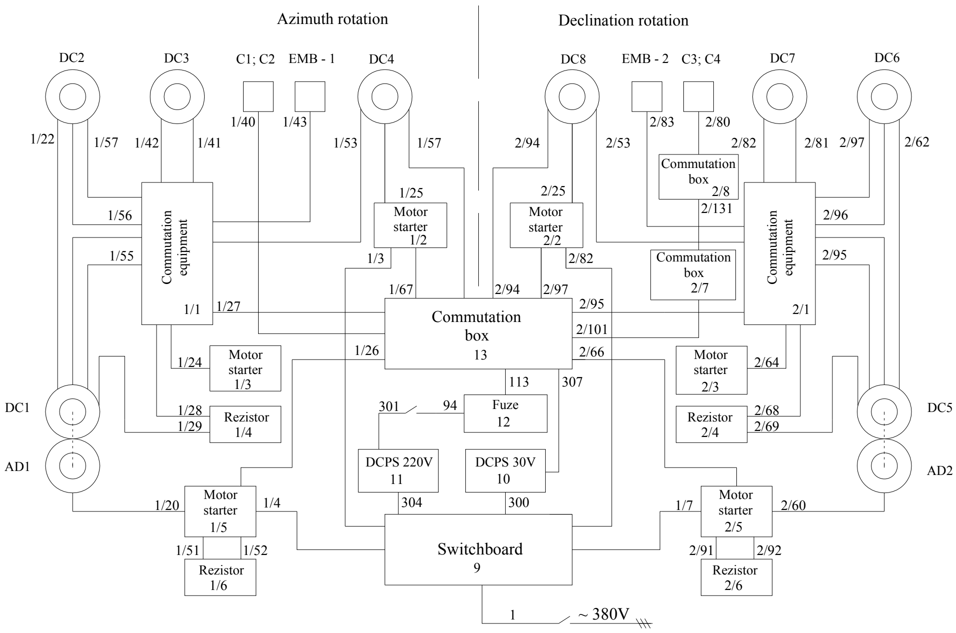

Fig. 9. Cabling scheme of power supply and antenna's azimuthal and elevation drive motors.

Originally, DC generators (DC1, DC5) were used as the regulated power supplies for fast drive motors DC2, DC6; these were driven by asynchronous motors AD1, AD2. Slow-motion motors DC3, DC7 were connected to amplidynes DC4, DC8, which were steered by tube amplifiers (built in the remote control desk).

4. DEVELOPMENT OF THE DC MOTOR CONTROL FOR THE EXPERIMENTS

Based on the results of studying the DC motor control system and especially the technical condition of the electrical machinery, apparatus and control of power supplies, it was decided that their renovation and use for the antenna driving is not reasonable.

To carry out the pilot studies and determine the technical characteristics, only low-speed drive motors (DC3, DC7) were restored. Power supply circuits for these motors, gearbox electromagnetic clutches (C1–C4), electromagnetic brakes

(EMB1, EMB2) and tachogenerators (TG1, TG2) were distributed among separate commutation boxes (15, 16). The new cable connection scheme for experimental studies is shown in Fig. 10.

As the power supply sources for DC motors, static four-quadrant DC converters (Siemens Simoreg DC-Master 6RA7013) were chosen. The technical parameters of the converters are given in Table 4.

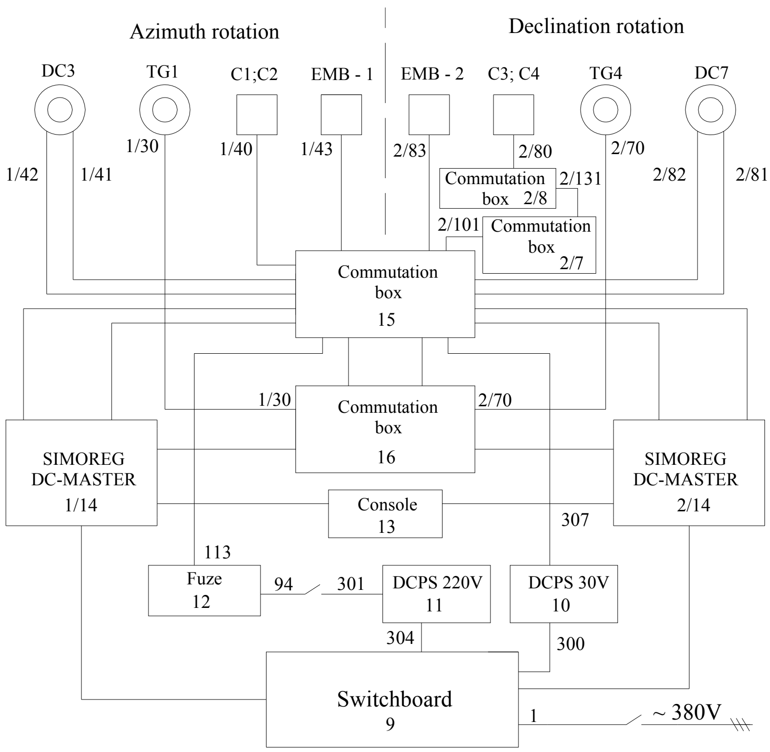

Fig. 10. Cabling scheme for studying the technical characteristics
of the antenna drive with DC converters.

Table 4

The main rated electric parameters
of the Siemens Simoreg DC-Master 6RA7013 converters

Number	Parameter	Value
1	Armature supply voltage, V	3·400
2	Armature supply current*, A	13.0
3	Field supply voltage, V	2·400
4	Armature DC voltage, V	0–420
5	Armature DC current, A	15.0
6	Armature supply overload capability *·**, %	180
7	Armature output power, kW	6.3
8	Field DC voltage, V	<325
9	Field DC current, A	3.0

* at the rated armature current
** load according to the operating instructions

The main features of Siemens Simoreg DC-Master 6RA70 series converters are as follows.

1) option for implementation of open- or closed-loop motor control circuit. The feedback corresponding to the current motor speed is effected by external signals (from analogue or digital speed sensors) or internal ones. With appropriate programming it is possible to build a proportional or an integral, or a proportional-integral, or a proportional-integral-derivative motor controller;
2) diversified protections, e.g.:
   - armature and field circuit current limiters;
   - temperature control for motors and thyristors; current limitation during normal operation and allowed overloads;
   - motor speed and torque limiters;
3) possibilities to control the converters either from the analogue inputs (current or potential) or digitally (for computer-aided converters);
4) possibility of programming the parameters from a simple control panel or of loading them from computer;
5) possibility to monitor the main parameters of motors as analogue signals on converters' corresponding outputs or as digital information for computer-aided monitoring;
6) built-in advanced procedures for automatic and manual optimization of the operating parameters .

Investigation into the drive's dynamic characteristics was carried out using the scheme presented in Fig. 11.

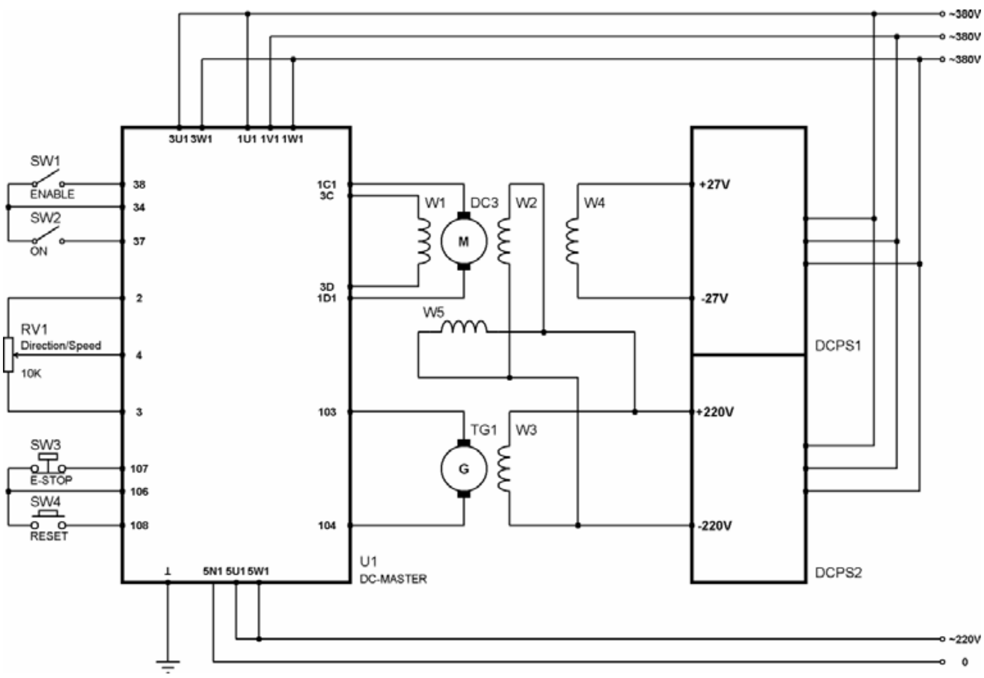

Fig. 11. Control scheme of the low-speed motor.

In Fig.11 the following elements are shown:

- U1 – converter;
- DC3 – slow motion DC motor (azimuthal axis);
- G1 – tachogenerator attached to DC3 motor;
- W1 – excitation winding of DC3 motor;
- W2 – DC3 brake reset winding;
- W3 – excitation winding of TG1;
- W4 – winding for gearbox electromagnetic clutch C1 of motor DC3;
- W5 – winding for main electromagnetic brake (EMB1) of the gearbox;
- SW1 and SW2 – "Enable operate" switches/"On/Off" safety switching;
- SW3 and SW4 – safety switch-off by push-buttons SW3 and SW4 for resetting the converter to the operating state after emergency shutdown;
- RV1 – potentiometer for setting the motor rotation direction and speed;
- DCPS1 –27 V DC power supply;
- DCPS2 –220 V DC power supply.

During the experiments, the converter was used as a proportional-integral motor controller with the derivative component only in the channel for the motor's current speed control (the manufacturer's default operating mode). The following parameters were programmed:

1) the main motor's parameters: the rated armature and field currents&voltages, rated rotational speed, temperature constant, etc.;
2) the maximum rotational speed and current speed for speed-dependent current limitation;
3) channel for selection of the current speed indicating signal; the channel parameters based on the results of tachogenerator calibration;
4) the field current control mode, the motor current and torque limiting values, the parameters of the ramp function generator.

As a result of verification tests it has been established that the rotational speed of drive motor DC2 controlled by a static voltage converter can easily be varied from 0 to 1000 rpm, with the maximum power of 600 - 800 W consumed by the drive unit for antenna's azimuthal rotation.

Applying Eq. (2), the angular velocity of azimuthal movement can be calculated as follows.

At a rotational speed of 1180 rpm and a given gear ratio 54400 of the low-speed drive, the angular velocity of azimuthal axis rotation will be

$$n_{az.} = \frac{1180\,\text{rpm}}{54400} \cdot 360^{\circ} = 7.82\ ^{\circ}/\min . \tag{3}$$

The converter with the maximum output voltage of 420 V allows steering (at a constant field current) the motors' DC3 and DC8 rotation speed in the range from 0 to 2250 rpm*. The employed earlier electromachine energy converters warranted

* According to the manufacturer's mechanical specifications, for the given type of motors the allowed rotational speed is up to 3300 rpm (see Table 2).

the control over the rotation speed for this type of motors in the range 0–1180 rpm. Using a static converter for the slow DC motor provides the antenna's azimuthal movement with the speed:

$$n_{az.\max} = \frac{2250}{54400} \cdot 360^{\circ} = 14.76\ ^{\circ}/\min. \tag{4}$$

Extension of the control range of motors' rotation speed could be useful for monitoring the space objects in near-earth orbits.

5. CONCLUSIONS

1. Prospects for the development of ERI VIRAC are associated with renovation of the antenna RT-16 (16-m radio-telescope) − the second fully steerable antenna located in its territory.
2. With support from ERDF, the ERI VIRAC infrastructure has been renovated and the reliability of electricity supply improved. The 30-km optical fibre cable provides the access to Geant (a high-speed data link network).
3. Based on the research results, circuit diagrams and layouts of the positioning system and antenna's basic unit have been worked out.
4. The accepted gear ratio of the antenna drive unit in azimuthal direction for the fast rotation motor is 850, while for the slow rotation motor − 54400.
5. The cabling scheme of power supply and drive unit motors has been designed.
6. To power the 2.6 kW DC motors, an experimental scheme of the antenna's drive unit with a static voltage converter (Simoreg DC-Master 6RA70) has been created.
7. The maximum power consumed by the drive unit for rotating the antenna in azimuthal direction at a DC motor's speed of 1000 rpm does not exceed 600-800 W.
8. The slow motor can provide the antenna's rotational speed in azimuth up to 14.76 °/min.

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IRBENES 16 m DIAMETRA PILNAS PIEDZIŅAS PARABOLISKĀS ANTENAS SAGATAVOŠANA RADIOASTRONOMISKAJIEM NOVĒROJUMIEM.

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K o p s a v i l k u m s

Inženierzinātņu institūta "Ventspils Starptautiskais Radioastronomijas Centrs" attīstības iespējas ir saistītas ar otrā tā teritorijā izvietotā radioteleskopa RT-16 pilnībā vadāmās paraboliskās 16 m diametra antenas darbības atjaunošanu.

Infrastruktūras rekonstrukcijas rezultātā ir paaugstināta elektroapgādes drošība, kā arī nodrošināta piekļuve augstas ātrdarbības datu pārraides tīklam Geant, izmantojot 30 km garu optiskās šķiedras sakaru kabeli.

Antenas azimutālā virziena ātrās pārvietošanas elektrodzinēja reduktora pārneses koeficients ir 850, bet lēnās pārvietošanas elektrodzinējam tā vērtība ir 54400.

Ir izveidota antenas azimutālās un augstuma pārvietošanas elektrodzinēju slēguma un elektrobarošanas kabeļu savienojumu shēma. Izstrādāta antenas piedziņas mehānismā izmantojamo 2,6 kW līdzstrāvas dzinēju darbības eksperimentālās izpētes shēma, pielietojot statisko sprieguma pārveidotāju Simoreg DC-Master 6RA70.

Antenas azimutālās pozicionēšanas gaitā piedziņas elektrodzinējam rotējot ar ātrumu 1000 apgr/min, tā patērētā jauda sastāda 600–800 W.

Lēnās piedziņas režīma elektrodzinējs spēj nodrošināt antenas pārvietošanu azimutālajā virzienā ar ātrumu 14,76 °/min.

10.02.2011.