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29 August 1980

USSR Report

ENERGY

(FOUO 17/80)

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USSR REPORT

ENERGY

(FOUO 17/80)

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ELECTRIC POWER

UDC 621.311.25:621.039.693

STRUCTURAL ELEMENTS OF FIFTH POWER UNIT OF NOVOVORONEZH AES

Moscow ENERGETICHESKOYE STROITEL'STVO in Russian No 6, Jun 80 pp 2-5

[Article by Engineers G. P. Fil'kova and V. S. Strel'nikova]

[Text] One of the basic structures involved in the main facility is the reactor division. It is a cylindrical building with an outside diameter of 47.4 meters, a height of 76.4 meters consisting of unsealed (to the 11.00 meter mark) and sealed (above the 11.00 meter mark) parts.

The sealed part -- a closed shell of cylindrical shape with gently sloping dome -- is designed to take forces which arise under the effect of the loads in the construction, operating and emergency periods and also localization of the consequences of a possible emergency and protection of the environment from radioactive contamination. The shell is designed for a maximum excess pressure of 0.415 MPa and a temperature of 150° C, and it is made of pre-stressed reinforced concrete with diagonal reinforcing of the cylinder. It consists of spatial reinforcing blocks 6 × 9 meters and weighing up to 10 tons with inside facing. Special mechanisms for putting tension on the reinforcing are installed at the top and bottom of the shell.

Strands of high-strength smooth wire 5 mm in diameter passed through polyethylene channel formers 225 mm in diameter have been used as the prestressed reinforcing. The channel formers are laid in three rows in the center of the concrete cross section of the cylinder.

The inside facing of the protective shell and the horizontal covering at the top of the floor at the 11.80 meter mark performs the function of a sealed loop containing the radioactive materials which could fill the shell in case of an emergency. The high quality of the welded joints of the sealed loop has been achieved as a result of strict observation of the requirements of the effective norms when performing the welding operations and during quality control of the welds.

In order to check the tightness of the welds used when installing the sealed loop by the helium probe method, special battens are placed along their length into which helium is pumped. Keeping the battens during the operating period permits periodic monitoring of the seal of the welded joints if necessary and timely detection and elimination of possible leaks. When testing the protective shell for tightness and seal, an excess pressure of up to 0.415. MPa has been created in it.

In order to check the condition of the facing of the domed section there is a special bridge used during installation, welding, quality control of the dome welds and painting it.

The inside structures of the sealed part of the shell are saturated with process conduits and foundation parts. When erecting the shell broad use is made of steel cells. A steel cell (see Figure 1) is a three-dimensional module of two facing sheets (the distance between them is equal to the wall thickness) joined by reinforcing elements for rigidity. The steelsheets 6-8 mm thick perform the functions of the working reinforcing, decking and facing. For coupling the steel sheets to the concrete, stays made in the form of angles and pins are provided. When necessary, in case of high loads, additional reinforcing 25-32 mm in diameter is installed with a spacing of 150 to 200 mm.

The length of the steel cell is 3-6 meters, its height is equal to the "floor" height (6-9 meters), and it weighs up to 15 tons.

The metal covering structure is the same module, but with one metal sheet at the bottom.

The inside structures of the sealed part of the reactor division are made basically also from steel cells with previously installed process conduits and special applied coatings. A total of 10,100 tons of steel cells have been installed in the fifth power unit of the Novovoronezh Nuclear Power Plant.

The application of industrial structural designs in the reactor division has led to significant reduction of labor expenditures at the construction site as a result of transfer of a number of operations to the plant (see the table).

In the reactor division, in addition to the steel cells there are also structures capable of withstanding high emergency loads. In particular, the wall of the overload pool is made in the form of a reinforced concrete structure with concealed steel beams. The floors and ceilings and the hatches above the steam generator facility have the same structural design. The execution of the floors and ceilings from reinforced concrete with ordinary reinforcing would be connected with great difficulties in view of the complexities of its configuration and the nature of operation. Accordingly, the floors and ceilings have been designed from metal box beams, the inside cavities of which are filled with concrete. The sections of the floors and ceilings between the metal beams are reinforced with rods welded to their edges. Thus, the metal beams serve as the bearing elements of the floors

Structural designs made of monolithic reinforced concrete		Steel shells	
At the plant	On the construction site	At the plant	On the construction site
Manufacture of reinforcing and forming modules	Installation of reinforcing and forming modules with welded joints	Manufacture of steel cells	Installation of steel cells
Manufacture of mounting parts and conduits	Installation of mounting parts and conduits	Manufacture of mounting parts and conduits	Welding of joints between cells
	Installation of forming slabs and scaffolding	Installation of mounting parts and conduits	Pouring concrete
	Pouring concrete	Application of the first finished layers	Final surface finishing
	Dismantling of the forms		
	Preparation of the surface		
	Priming the surface		
	Final finishing of the surface		
	Dismantling the scaffolding		

and ceilings, and the concrete performs the functions of biological shielding. The box bearing beams are arranged in such a way that they also simultaneously frame the hatch openings over the steam generators.

The covers of the large hatches over the steam generators were previously made all-metal, which complicated their transportation and operation and maintenance. The excess pressure under the hatches required the application of seals and cut-offs which were complicated to manufacture and maintain. Therefore the decision was made to make the hatch covers in the form of metal box structures (they serve as the bearing elements) filled with concrete which performs the functions of biological shielding. Under loads

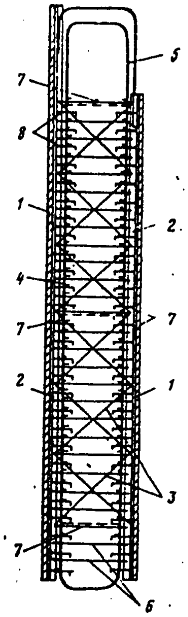

Figure 1. Steel cell with two-sided sheet and rod reinforcing. 1 -- steel sheet; 2 -- angle stay; 3 -- vertical diaphragm rods; 4 -- reinforcing rod; 5 -- reinforcing projections into the floors and ceilings; 6 -- cross reinforcing; 7 -- horizontal diaphragm; 8 -- stays.

directed downward, the hatch covers rest on the floor in ordinary grooves. Under loads created under excess pressure and directed upward, the hatch covers are held in place by metal plates welded to the frames of the hatch covers and the framing in the opening. The seal of the space between the hatch cover and the floor is insured by installing battens above and below the floor welded along the outline of the hatch by water-gas impermeable welds.

Among the basic structures making up the main facility is also a special facility. The inside structure of the special facility was designed from three-dimensional modules -- the so-called reinforced concrete cells.

These structural elements are made in the test area as follows. Making a three dimensional reinforcing module 6 × 3 meters in size and weighing about 20 tons, it is equipped with the necessary process conduits. After double submersion of the structural element (on both sides) in the form with the concrete and further treatment of it in a steam chamber, the hollow three-dimensional module -- reinforced concrete cells -- is ready for transportation and installation where it is going to be used. The thickness of the concrete layer of the module is 7 cm. After installing several such wall type reinforced concrete cells and installing the joining reinforcing, the hollow space inside the cells is filled with concrete using vibrators (Figure 2). Thus, structural integralness of the biological shielding (without welds and cracks) is insured along with its industrial nature and, the main thing, a reduction in the expenditures of labor. The latter is achieved as a result of exclusion of the operations with respect to installation and dismantling the special forms inasmuch as the reinforced concrete cells themselves serve as the form and also in connection with the fact that the laid process conduits are installed in the test area.

Further improvement of the structural design of the reinforced concrete cells will be promoted by the application of special coatings in the test area.

The volume of the reinforced concrete cells manufactured in the construction of the special facility for the fifth power unit for the wall and floor structures was 17,000 and 6000 m^3 respectively or 81% of the total volume of the structural elements of the special facility.

The list of operations performed at the plant and at the construction site when using the steel cells and structural elements of monolithic reinforced concrete is presented in the table.

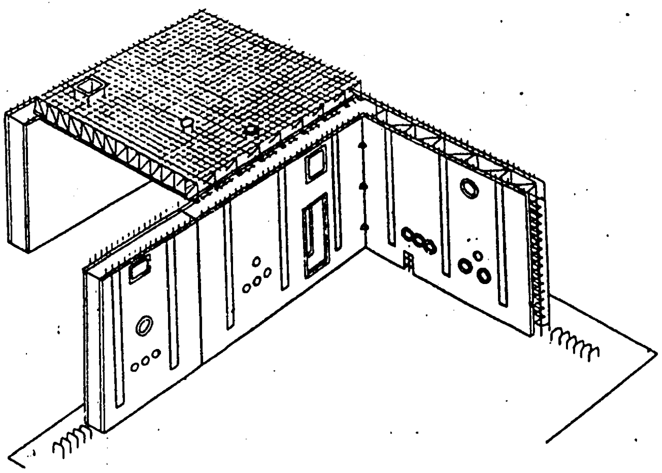

Figure 2. Fragment of the wall and ceiling made of reinforced concrete cells.

The tanks for storing radioactive liquids are completely or partially lined with carbon or corrosion-resistant steel (depending on the purpose of the facility). The lining is a welded steel sheet 3-4 mm thick fastened in the concrete by various stays welded to it. Increased requirements are imposed on the tightness of the lining welds.

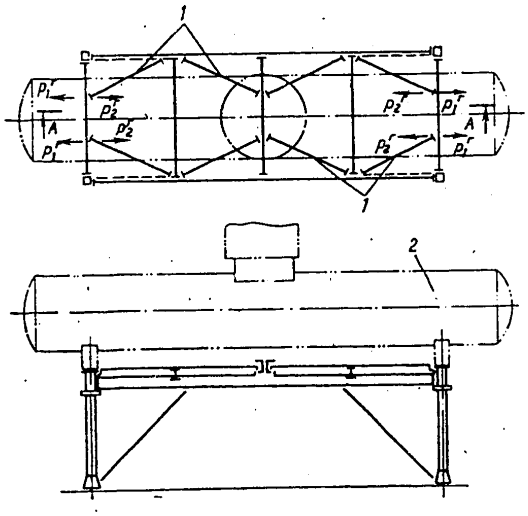

Figure 3. Diagram of the beam cage. 1 -- brace and tension member, 2 -- deaerator.

The individual facilities have double lining, the structural design of which permits discovery of leaks and determination of the location of the leak. For example, between the layers of the double steel lining of the floor of the holding and overload basins there is draining concrete which permits organized removal of the leaked material. The two layers of the lining are connected to each other so that there is a space between them into which inert gases are pumped for quality control of the welds after installation of the linings and during operation of the electric power plant. This offers the possibility of operative detection of the location of a leak in the lining and reduction of the repair time. In addition, when creating pressure between the lining layers that exceeds the pressure of the liquid it is possible to stop such leaks.

In contrast to the ordinary grooved decking, the decking of the "dirty" facilities outside the protective shell is made of smooth sheet material with spot welding of the channels onto the smooth sheet.

By the strict operating conditions of the facilities of the reactor division, increased requirements are proposed on the finishing of their surfaces. The surfaces of the sealed metal shell are protected by an epoxy coating with preliminary aluminum plating. The surfaces of the facilities subjected to the constant effect of radioactive and chemically active liquids and also the surfaces inaccessible for inspection and repair during operation and maintenance of the nuclear power plant have a lining of corrosion resistant steel.

The machine room and deaerator module are also basic structures of the main facility. They are in the form of a building that is rectangular in plan view 156 × 63 meters in size.

The metal supporting frame is formed by the multistory frames of the module stack and the frames of the machine room adjacent to them. The columns and bars of the stack are designed to be solid-wall with rigid support. The upper units for supporting the machine room frames are hinged. The stability of the frame in the transverse direction is insured by the rigid frame of the stack; in the longitudinal direction, by the installation of vertical couplings and braces between the columns.

For the columns of the frame and the bars of the stack, 16G2AF steel with increased strength was used instead of low-alloy steel. This made it possible to save about 20% of the metal when building the frame (by comparison with making the frame from low-alloy steel). When erecting the frame, adjustment-free installation of the columns and preliminary consolidation of them into installation modules at the construction site were realized.

The girders of the machine room are trapezoidal in outline with triangular web. The booms and struts of the girders are made of 10G2S1 steel. Twelve-meter insulated plates made of shaped steel sheet were used for the floor covering. The crane beams under two 125 ton cranes were split, made of 10G2S1 steel.

In the supporting structures under the deaerators a system of beams and tension braces was used to exclude the horizontal loads on the bearing beams and posts. This extinguishes the horizontal forces from the thermal displacements of the support of the deaerator tank (see Figure 3).

Standard foundations made of prefabricated reinforced concrete of the light type for the supporting walls -- prefabricated panels -- were used as the foundations of the A and B column frames.

In all of the structures of the main facility, underground hydraulic insulation made of shaped polyethylene was used, which made it possible to reduce the expenditures of labor on the construction and to improve the reliability of the structures of the main facility.

The auxiliary structures (such as the sanitary and administrative facilities, passageways, and so on) were, as a rule, completely made of standardized prefabricated elements.

The structure of the fifth power unit of the Novovoronezh Nuclear Power Plant is a new phase in the construction of nuclear power plants with water-cooled, water-moderated reactors.

The increase in unit power and the application of improved component and technical designs in the fifth power unit with the VVER-1000 water-cooled, water-moderated power reactor by comparison with the power unit with the VVER-440 reactor made it possible to insure the following (on reduction to the corresponding power):

A decrease in size of the production buildings by 30%;

A reduction in the labor expenditures on erecting the basic structures by 10-13%;

Reduction of the stainless steel used when building the structural elements by 30% and also the concrete and reinforced concrete by 8%.

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ELECTRIC POWER

UDC 621.311.25:621.31.002.2;624.074.4.627.07

BASIC STRUCTURAL, PROCESS DESIGNS OF MAIN POWER UNIT OF VVER-1000 REACTOR

Moscow ENERGETICHESKOYE STROITEL'STVO in Russian No 6, Jun 80 pp 5-18

[Article by Engineers S. L. Belokhin, A. K. Belyanichev, Architects B. I. Kartashev, B. B. Kim, Engineer Ye. V. Minayev, Architect V. G. Sheynkman, Engineers R. K. Kozochkin, A. Z. Krichevskiy, Candidate of Technical Sciences Yu. G. Khayutin, and Engineers I. S. Vinogradov, and D. V. Prozorovskiy]

Architectural Planning of the Power Unit[1]

The placement of the buildings and structures of the main power unit of the VVER-1000 water-cooled, water-moderated power reactor (the fifth unit of the Novovoronezh Nuclear Power Plant) on the master plan was determined by their process and transport interconnection, the relief of the terrain, and the territorial arrangement of the industrial site (see Figure 1).

The adopted design provided for the arrangement of the buildings and structures of the nuclear power plant on two mutually perpendicular axes. The main axis was located parallel to the longitudinal axis of the machine room and passes through the main facility, the crosswalk and the sanitary-housekeeping facility, separating the structures into the zones of the primary and secondary circuit (strict and free regimes, respectively). The axis perpendicular to the primary axis passes through the area in front of the plant, the administrative building, the second crosswalk and the sanitary-housekeeping facility.

As a result of the complexity of the relief of the site, the area in front of the plant and the industrial site are on different levels. The area in front of the plant, which is at the level of the road, is used for access of public and private transportation to the administration building. The railroad and the truck route for reaching the industrial site are on the

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[1] This section of the article was written by architects B. I. Kartashev, B. B. Kim and V. G. Sheynkman.

lower level. The pedestrian walkways and service paths are clearly marked and do not intersect.

The three-dimensional planning of the complex includes the terraced levels, the retaining walls, stairs, fixed ramps and small architectural forms.

The central group of structures of the power unit is made up of three basic facilities joined by crosswalks: the main facility, sanitary-housekeeping and administrative facilities.

The most significant with respect to size is the main facility (see Figure 2) joining the machine room and the deaerator stack (the free regime zone), the reactor division and the special facility (the strict regime zone).

The reactor division is located inside the right angle formed by the machine room and the special facility. In order to localize the consequences of possible emergencies, this structure is made in a protective prestressed monolithic reinforced concrete shell with inside sealed metal lining. The shell is a vertical cylinder 47.4 meters in diameter, 76.4 meters high with a gently sloping dome.

The machine room is made in the form of a rectangular building 51 × 156 meters in plan (13 spans of 12 meters each) and 32.4 meters high. The composition of the machine room provides for the possibility of placement of heavy equipment in the range of the bridge crane and railroad siding. The railroad spur is located on the permanent end.

Two turbounits with side condensers installed in this building have transverse arrangement with a main service elevation of 5.60 meters. The supporting frame of the machine room is metal; it is formed of transverse frames installed with a spacing of 12 meters in the longitudinal direction. It is adjacent to the metal frame of the multistory deaerator stack. The roofing is made of insulated 12-meter panels manufactured with the application of shaped steel sheeting. The floors and ceilings of the machine room were made of prefabricated corrugated reinforced concrete slabs 3 × 3 meters in size at the zero datum; the wall enclosure is made of prefabricated claydite concrete panels and VAZ lighting panels.

The deaerator stack is a rectangular building 12 × 156 meters in plan view and 46.8 meters high. It is adjacent to row B of the machine room. The electrical engineering devices are placed at the elevations from -4.10 to +9.80 meters. The frame of the stack is metal, it is formed of transverse frames installed with spacing of 12 meters. The floors and ceilings are formed of standardized pre-stressed reinforced concrete slabs with 12-meter span.

The special facility is adjacent to the reactor division and the deaerator stack. It is a prefabricated monolithic reinforced concrete building 75 meters wide and 85 meters long consisting of 5 spans of 15 meters each.

On the longitudinal side there is a railroad spur common with the reactor division. In the special facility are the process systems servicing the reactor division, the "dirty" workshops for repairing the equipment from the primary circuit, the fresh and spent fuel storages, the solid and liquid waste storages, and the exhaust ventilation center.

The composition of the set of structures of the fifth power unit of the Novovoronezh Nuclear Power Plant has the following advantages:

Compact planning;

Clear separation of the main facility into "clean" and "dirty" zones;

Reduction of the extent of the "dirty" process couplings of the primary circuit as a result of blocking of the reactor division and the specialized facility;

Limitation of the paths of transportation of the "dirty" equipment to the workshop to the boundaries of the "dirty" zone;

Clear separation of the pedestrian ways of the "clean" and "dirty" zones but also inclusion of intersection of these paths with the service and transport paths.

In the opinion of the authors, further improvement of the layout of the nuclear power plants with VVER [water-cooled, water-moderated power reactors] reactors must proceed along the path of developing a standardized monolithic unit, improvement of the efficiency of the composition by maximum blocking of the process system (above all, the safety systems) considering the optimal process relations and also a decrease in the overall dimensions of the equipment and broad application of consolidated industrial plant manufactured structural products.

Development of the Structural Design for the Protective Shell[1]

One of the most complex problems which had to be solved when designing the main VVER-1000 power unit was the development of the structural design for the protective shell of the reactor division intended for localization of a possible emergency in the primary coolant circuit (see Figure 3). In case of a rupture of the primary circuit when the pressure of the vapor-gas mixture in the reactor division can reach 0.5 MPa, the protective shell must maintain the seal (the admissible leakage of the vapor-gas mixture of no more than 0.1% for 24 hours after the emergency). The load from the pressure of the vapor-gas mixture on the walls and the floors and ceilings of the shell will be about 5000 MN. The tensile stresses can reach 10 MN per

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[1] This section of the article was prepared by Engineers Ye. V. Minayev, S. L. Belokhin, A. K. Belyanichev, A. Z. Krichevskiy, and Candidate of Technical Sciences Yu. G. Khayutin.

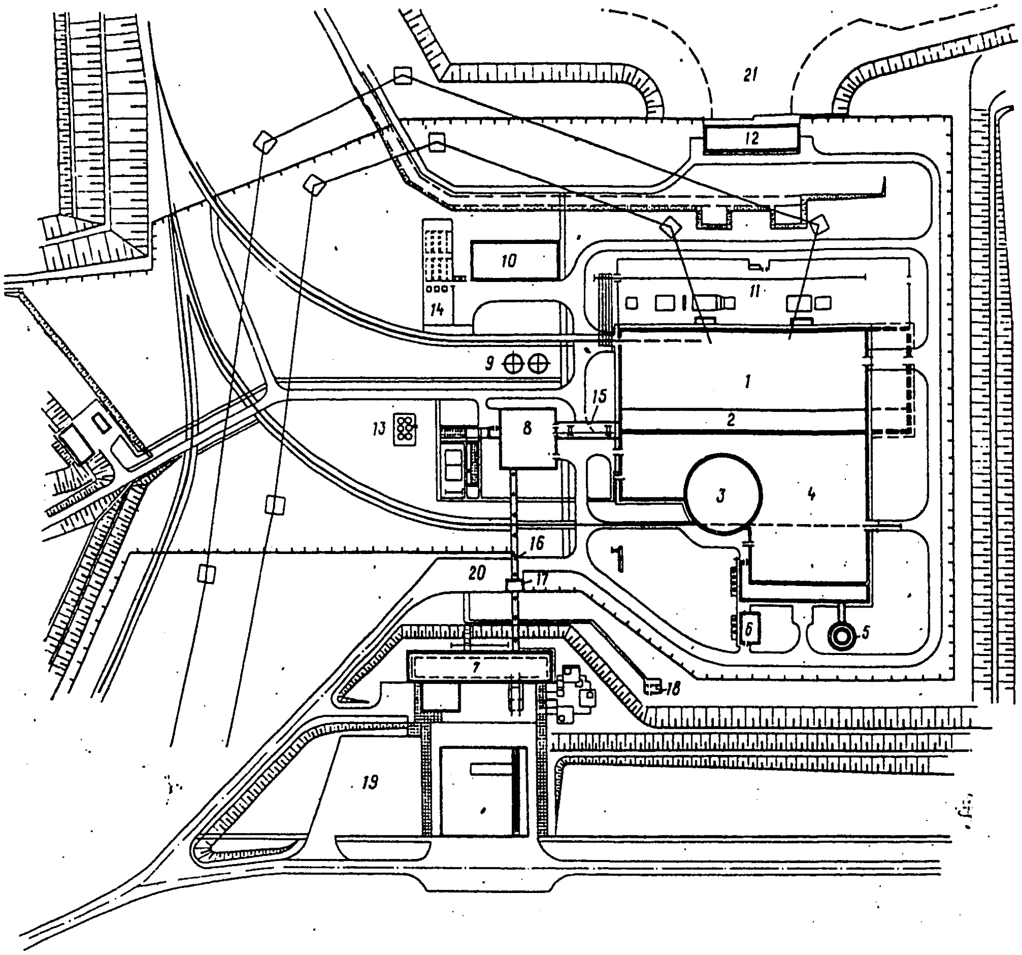

Figure 1. Master plan of the fifth unit of the Novovoronezh Nuclear Power Plant. 1 -- machine room; 2 -- deaerator stack; 3 -- reactor division; 4 -- special facility; 5 -- ventilation pipe; 6 -- compressor; 7 -- administrative facility with mess; 8 -- sanitary-housekeeping facility; 9 -- desalinated water tanks; 10 -- diesel generator; 11 -- outdoor transformer installation; 12 -- pumping station; 13 -- nitrogen and hydrogen receivers; 14 -- diesel fuel area; 15, 16 -- crosswalks; 17 -- passageway; 18 -- sewage pumping station; 19 -- parking area; 20 -- access to the plant territory; 21 -- cooling pond.

meter of wall with an inside diameter of 45 meters and a height of the shell up to 76 meters.

There are several basic structural designs for the shells corresponding to the indicated requirements.

On the basis of the results of analyzing the designs of shells existing in world practice by specialists of the Teploektroproyekt Institute, a version of a prestressed reinforced concrete shell was adopted. With respect to the level of prestressing (5000 to 10,000 kN per meter of wall), tensile force of the reinforcing elements (to 10,000 kN each), the total volume of prestressed reinforcing (about 1600 tons for one structure), the prestressed protective shell of the reactor division of the fifth power unit of the Novovoronezh Nuclear Power Plant has no analogs in Soviet construction.

When developing the structural design of the main protective shell, considering the necessity for conversion in the near future to series erection of such shells, it was necessary to provide for the possibility of constructing them by industrial methods in the shortest possible time and with minimum expenditures.

By assignment of the master planning agency -- the Teploelktroproyekt Institute -- the model and the theoretically calculated studies of the stressed state of the structure was performed by the NIIZhB [Scientific Research Institute of Reinforced Concrete], the LPI [Leningrad Polytechnic Institute], and Gidroproyekt. The construction technology and the nonstandard equipment for erecting the shell were developed by the Orgenergostroy Institute[1]. The problems connected with building the nonstandard equipment were also studied by the PKB [Design and Construction Office]of Glavenergostroymekhanizatsii and the Gidrospetsproyekt Institute.

On the basis of the results of scientific studies, technological developments and preliminary analysis of the basic structural designs it was necessary to select a configuration of the protective shell which was optimal from the point of view of the stressed state and construction technology, to define the parameters of the basic assemblies, select the optimal arrangement of the reinforcing elements and their structural design and also determine the bearing capacity and the method of anchoring the reinforcing elements.

During the process of the investigation the study was made of several schemes for arranging the reinforcing elements -- orthogonal, helicoidal (see Figure 4), helicoidal-loop, orthogonal-loop, and so on. It was established here that each of the investigated designs has both structural-process advantages and deficiencies [1, 2]. The results of the structural calculations and the technical-economic analysis permitted establishment of

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[1] The most complicated set of problems connected with creating the prestressing system was resolved in several versions by the Orgenergostroy and the Gidroproyekt Institutes (the prestressing system created by the Orgenergostrom was adopted for production).

the fact that the basic factors determining the competitiveness of the compared versions of the structure are losses of stress as a result of friction of the curvilinear reinforcing elements against the channel formers and also the ratio of the cost of the anchoring structures in 1 meter of stressed reinforcing elements. Here, if the indicated ratio for the anchor attachments of various types and reinforcing elements of different designs varies within relatively small limits, the stress losses as a result of friction and the overconsumption of basic materials connected with them can vary significantly depending on the angles of bending of the reinforcing elements and the friction coefficient. By the technical-economic calculations, the efficient areas of application of the various reinforcing systems presented below were established (as a function of the friction coefficient μ):

$\mu > 0.2$	Orthogonal layout with 4-6 pilasters
$\mu = 0.08$ to 0.2	Orthogonal-loop layout with 3 pilasters; helicoidal
$\mu < 0.08$	Helicoidal-loop

For determination of the friction coefficient of the stressed reinforcing elements of various types under conditions approaching natural conditions to the maximum, dugout test stands in the form of full-scale fragments of the shell were built [3]. More than 70 tests of the reinforcing elements were run on the spans with calculated tension of 2400 to 10,000 kN. Reinforcing elements were tested in the form of bundles of parallel, smooth high-strength wires (free-lying and with periodically installed couplers and polyethylene channel forming tubes both without lubricant and with high-consistency lubricant greases (graphite and gun lubricant). The minimum losses of stress from friction ($\mu \approx 0.08$) were obtained when testing bundles of parallel free-lying wires using PVK gun lubricant as the antifriction and anticorrosion compounds. During the tests it was established that the complexity and vapor consumption of the anchoring of the wires and strands increased with an increase in the unit power of the reinforcing element. The structural design of the continuous coiling reinforcing element with thimble anchoring was proposed as an alternative solution. The tests run on these reinforcing elements with calculated tension of 10,000 kN demonstrated their high aggregate strength (a coefficient of unit strength 0.94 to 0.96) [4].

As a result of the performed scientific research and planning and design developments in the working design of the protective shell of the main power unit with the VVER-1000 reactor, a helicoidal (with optimal angle of $\theta = 35°15'$) layout of the stressed reinforcing elements in the form of two-loop continuous coiling bundles of 450 parallel free-lying high strength wires 5 mm in diameter was adopted. The calculated force of the prestressing of each bundle was 10,000 kN. The reinforcing bunches are installed in polyethylene channel forming tubes molded in the walls and the dome of the shell (with shifting to the outside surface of the walls). In the vertical walls of the shell the channel formers are arranged in three rows: in outside and inside layers, with left-hand thread of the helical line, and in the middle layer, with right-hand thread. For the dome provision was made for a two-layer arrangement of the channel formers crossing at a right angle. The anchoring of all of the reinforcing bunches was on the rigid upper cornice and in the tunnel under the supporting bottom of the shell. Each of the bundles was put under tension from one direction. The anchoring was staggered; each of the two installed rows of bunches was equipped with tension anchors from opposite ends, as a result of which uniform tension of the structure was insured considering the friction of the bunches against the channel formers. The joints of the vertical walls of the shell with the floors and ceilings were made rigid, with developed transverse cross section of the upper cornice of the lower bracket. The reinforcing of the shell was made of large three-dimensional reinforcing modules including the outside and inside reinforcing grids, the sealing lining, the stiffening girders made of shaped rolled products and the channel former sections. M400 concrete was used for all of the structural elements of the protective shell.

As a result of the successful solution of the broad set of scientific research and planning and design problems, the developed structural design of the protective shell of the power unit with the VVER-1000 reactor corresponds fully to the effective international norms, and with respect to the primary parameters it is not inferior to the foreign structures built in recent years.

When developing the structural design for the shell, Soviet experience in the industrial erection of structures from large installation modules with a high degree of factory prefabrication was taken into account (Figures 5, 6). All of the structural elements of the shell were made of Soviet material. The construction and installation operations (including the set of operations with respect to manufacture, installation and prestressing of the reinforcing cables) were realized using Soviet process equipment, a significant part of which was created in the process of constructing the shell.

The construction and prestressing of the protective shell in the fifth power unit of the Novovoronezh Nuclear Power Plant were completed in August 1979. The experience in erecting it completely confirmed the expediency of the adopted structural-process solution, and the results of the testing under emergency pressure confirmed the reliability of the structure itself. At the present time analogous shells are being erected at the sites of the first phase of the Southern Ukrainian and Kalinin Nuclear Power Plants (two power modules each).

The experience obtained as a result of developing the first prospective shell permits operations at the present time with respect to the creation of prospective structural elements for the shells.

Prestress System with Calculated Tensile Force on the Reinforcing Cables of 10,000 kN[1]

When building a pilot power unit with a VVER-1000 reactor, the necessity arose for creating a prestressing system with a tension on the

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[1] This section was written by Engineer A. Z. Krichevskiy.

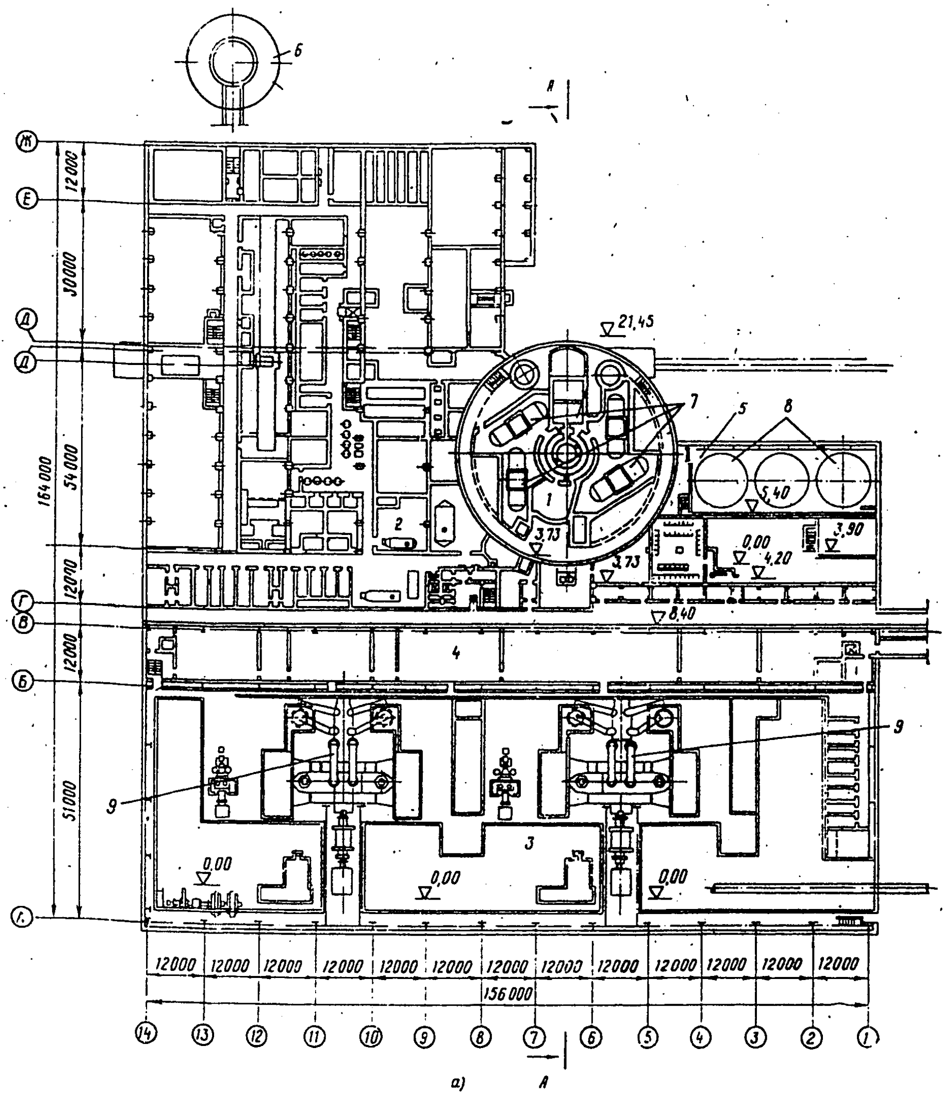
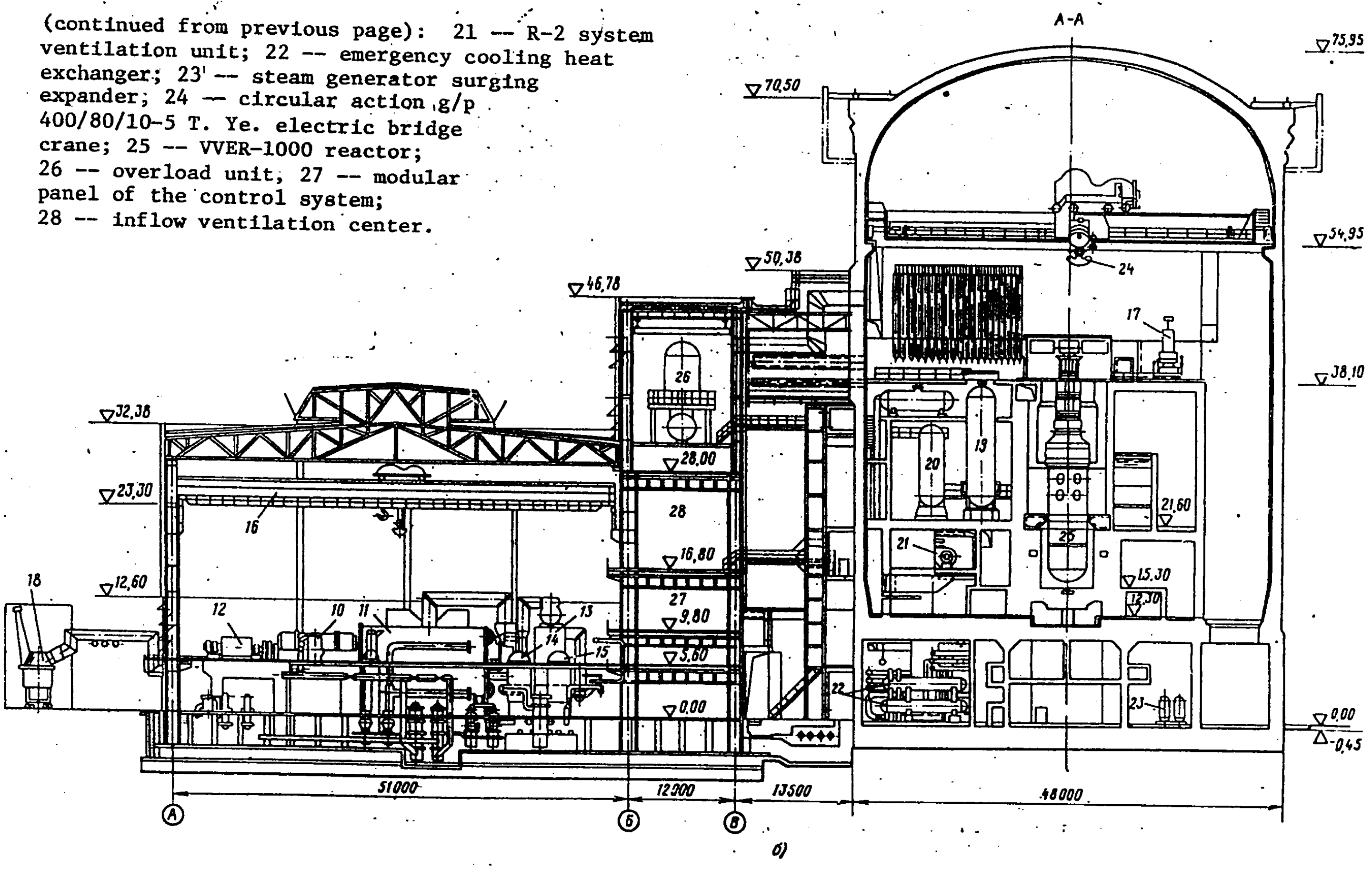


Figure 2. Plan view (a) and section (b) of the main facility of the fifth module. 1 — reactor division; 2 — special facility; 3 — machine room; 4 — deaerator stack; 5 — structure for emergency storage of boron; 6 — ventilation tube; 7 — steam generators; 8 — tanks for storing boron; 9 — turbines; 10 — generator; 11 — condenser; 12 — activator; 13 — separator and steam superheater; 14, 15 — low-pressure water heaters Nos 3 and 4; 16 — KM125U2/P125/20/5 electric bridge crane; 17 — deaerator; 18 — transformer; 19 — volume compensator; 20 — hydraulic tank; (continued next page).

(continued from previous page): 21 -- R-2 system ventilation unit; 22 -- emergency cooling heat exchanger; 23' -- steam generator surging expander; 24 -- circular action g/p 400/80/10-5 T. Ye. electric bridge crane; 25 -- VVER-1000 reactor; 26 -- overload unit; 27 -- modular panel of the control system; 28 -- inflow ventilation center.



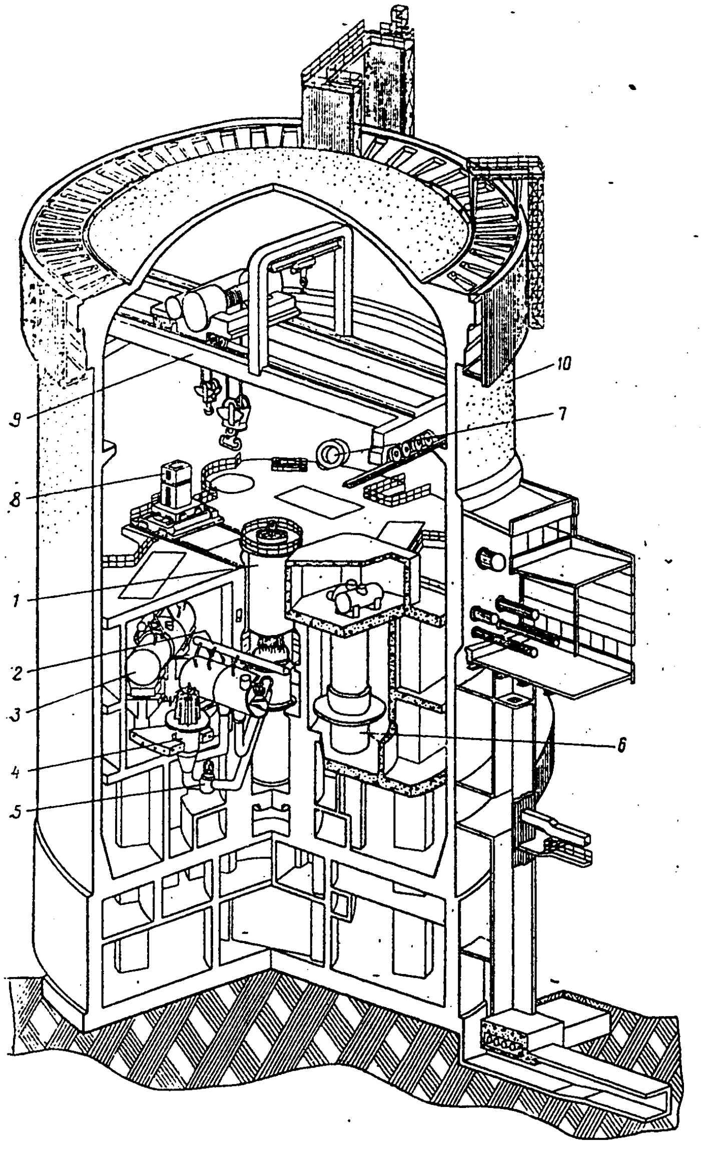


Figure 3. Reactor division of the power unit with VVER-1000 reactor. 1 — reactor; 2 — steam lines; 3 — PGV-1000 steam generator; 4 — main circulating pump; 5 — cutoff plate; 6 — volume compensator; 7 — escape lock; 8 — overload unit; 9 — 400 ton bridge crane; 10 — protective shell.

reinforcing cables of 10,000 kN. Accordingly, at the Orgenergostroy Institute a system was developed including two-loop reinforcing cables [3, 4] blind and tension anchors, the mounting parts of the anchor assemblies (the anchor blocks), the channel formers, hydraulic jacks, the pumping stations with monitoring and control systems (see Figure 7). In addition, the process of prestressing the reinforced concrete structures using this system and broad nomenclature of specialized equipment were created which permitted mechanization of the processes of the manufacture and installation of the reinforcing cables, the channel former sections and anchors and also the processes of putting them under tension and preserving them.

The technical specifications of the two-loop reinforcing cables made for the protective shell of the pilot power unit with VVER-1000 reactor are presented below:

Calculated prestressing	10,000 kN
Rupture force	14,000 kN
Weight of 1 meter of cable	70 kg
Cable diameter (with respect to the leading fittings)	130 (185) mm
Number of wires in the central crossection	450
Number of layers of wire on the loop sections	10-12
Wire diameter	5 mm
Ultimate strength of the wire	1.7 mPa

As the channel formers, tubes are used with a diameter of 225 mm and a wall thickness of 5.5 mm made of high-strength polyethylene (PVP type L). The ultimate tensile strength of the PVP is 20-40 MPa, the density is 0.94 to 0.96 g/cm^3, the weight of 1 meter of tubing is 3.94 kg [5].

Before installation, the tubes are assembled into sections 6 and 12 meters long which are heated and bent so that the radius of their curvature will be 34 meters. By using hot upsetting, one end of each section is shaped like a cylindrical bellmouth. During the installation mounting of the tubes the bellmouth is heated and pressed on the free end of the adjacent section. The bellmouth technique is used also to join the channel formers with the mounting parts of the anchor assemblies (the anchor blocks) made of two coaxial seamless tubes with supporting plates normal to their longitudinal axis.

Tension and blind anchors are installed on the anchor blocks.

The tension anchor consists of an oval thimble with through transverse opening for joining to the hydraulic jack, a threaded sleeve and shaped nut for fixing the reinforcing element in the stressed state. Before the beginning of tension, the threaded sleeve is installed inside the anchor block, and the shaped nut, outside in such a way that its end surface is fitted against the supporting plate. The loop of the reinforcing cable laid on the upper surface of the thimble enters the channel former through the opening in the hollow threaded sleeve where the wires are grouped into a tight bunch.

The blind stationary anchors are made of two parts -- the teardrop insert and distributing bushing with shaped opening for the loop section of the reinforcing cable encompassing the insert.

The basic parameters of the tension (in the numerator) and the blind (in the denominator) anchors are presented below:

Calculated load	11,000 to 10,000 kN
Maximum fixed drawing (travel)	750/-- mm
Length	1250/500 mm
Diameter	480/380 mm
Mass	820/225 kg

The tension of the reinforcing cables is realized by the DG-1000/800 four-cylinder hydraulic jacks which develop a force of 10,000 kN under a pressure of the working fluid in the hydraulic system of 34 MPa (see Figure 8). The cylinders are made three-chamber, which permits summation of the tensile forces when feeding the operating fluid simultaneously to the pressure chambers of the hydraulic jack housing and the plunger. The liquid exerts a pressure simultaneously on the front and rear covers of the plunger, causing advancement of it. The plungers are retracted when the middle return chambers are filled with the working fluid, and the pressure chambers are connected to the drain line. The like chambers of all four hydraulic cylinders are combined by the parallel scheme using annular manifolds connected to the pumping station by high pressure flexible hoses. The hydraulic cylinders are arranged in a row joined in pairs by rigid diaphragms with through transverse openings for installing the pin. After sliding the hydraulic jack over the thimble of the tension anchor the pin is inserted by the pressing mechanism into the openings of the hydraulic jack housing and the thimble and they are joined together.

During the tension process when feeding the working fluid under pressure to the pressure chambers of the hydraulic jack the plungers rest on the supporting plate of the anchor block, and the housing of the hydraulic jack connected by the pin to the thimble of the tension anchor is shifted backward, pulling the threaded bushing out of the anchor block. Here the locking nut withdraws from the mounting part, and it must be fitted tightly against the bearing plate as the reinforcing element is drawn.

The basic parameters of the hydraulic jack are presented below:

Calculated tractive force (under a working fluid pressure of 34 MPa)	10,000 kN
Travel:	
Maximum (without binding)	800 mm
With binding	1500 mm
Pressure in the hydraulic system (maximum)	40 MPa
Weight of the jack (dry)	3 tons
Overall dimensions (with plungers retracted):	
Length (including the manifold)	1460 mm

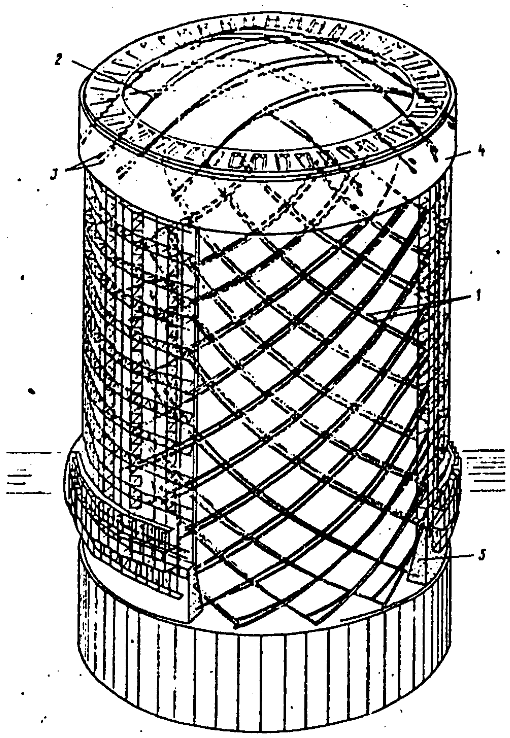


Figure 4. Schematic of the arrangment of the prestressed reinforcing in the protective shell of the pilot power unit. 1 -- helicoidal reinforcing cables installed in the vertical walls of the shell; 2 -- reinforcing cables installed by the orthogonal system in the dome of the shell; 3 -- tension and blind anchors; 4 -- upper cornice; 5 -- lower bracket.

Width (without mechanism for pressing the connecting pin)	645 mm
Height	970 mm
Diameter of the connecting pin	160 mm

As a result of the presence of several replaceable devices for joining to various types of tension anchors, the DG-1000/800 hydraulic jacks can be used for prestressing not only two-loop reinforcing cables with continuous coiling, but also bunches of individual sections of wires or strands. The application of the long-stroke cylinders and the possibility of binding the anchors of all systems permit putting tension on reinforcing cables 500 to 600 meters long.

The feed of the working fluid to the hydraulic jacks is accomplished using submersible pumps (NS-400/100). The basic units of this pump are mounted on the horizontal panel installed on the upper flange of the rectangular oil tank as a cover. The flanged electric motors are mounted on the panels for driving the high and low pressure pumps, the pressure gages, the control valves of the high pressure system, the arms of the hydraulic distributor of the low pressure hydraulic system, the fill tube with cover and breather, the input lines and the adjustment nuts of the safety valves. The high and low pressure hydraulic pumps are attached to the bottom of the panel by supporting brackets (in the operating position these pumps are submerged in the oil). The pumps are connected to the electric motors by vertical shafts. The oil lines, safety valves, low-pressure hydraulic distributor and oil filters are also attached to the bottom of the panel.

The basic parameters of the NS-400/100 pumps are presented below:

Maximum pressure in the delivery lines:	
High pressure	40 MPa
Low pressure	10 MPa
Hydraulic pump feed (at 1400 rpm):	
High pressure	1.6 liters/min
Low pressure	14.0 liters/min
Capacity of the oil tank	220 liters
Installed capacity of the electric motors[1]	4.4 kilowatts
Overall dimensions of the pump:	
Length	800 mm
Width	600 mm
Height	975 mm
Weight:	
Dry	250 kg
Operating	420 kg

For the protective shell the Construction Administration of the Novovoronezh Nuclear Power Plant has built 260 two-loop reinforcing cables 45 to 108 meters long weighing a total of 1620 tons. The Glavenergostroymekhanizatsii plants have delivered 520 tension and blind anchors with a calculated load of 10,000 kN. The Solnechnogorskiy experimental complex has manufactured six sets of hydraulic jacks and high-pressure pumps. All of the prestressing system elements have been tested under production conditions and recommended for broad utilization (Figures 9, 10).

At the present time centralized production of the two-loop reinforcing cables has been organized.

The investigated prestressing system can be used both in power engineering construction (when erecting reinforced concrete reactor vessels, arch dams,

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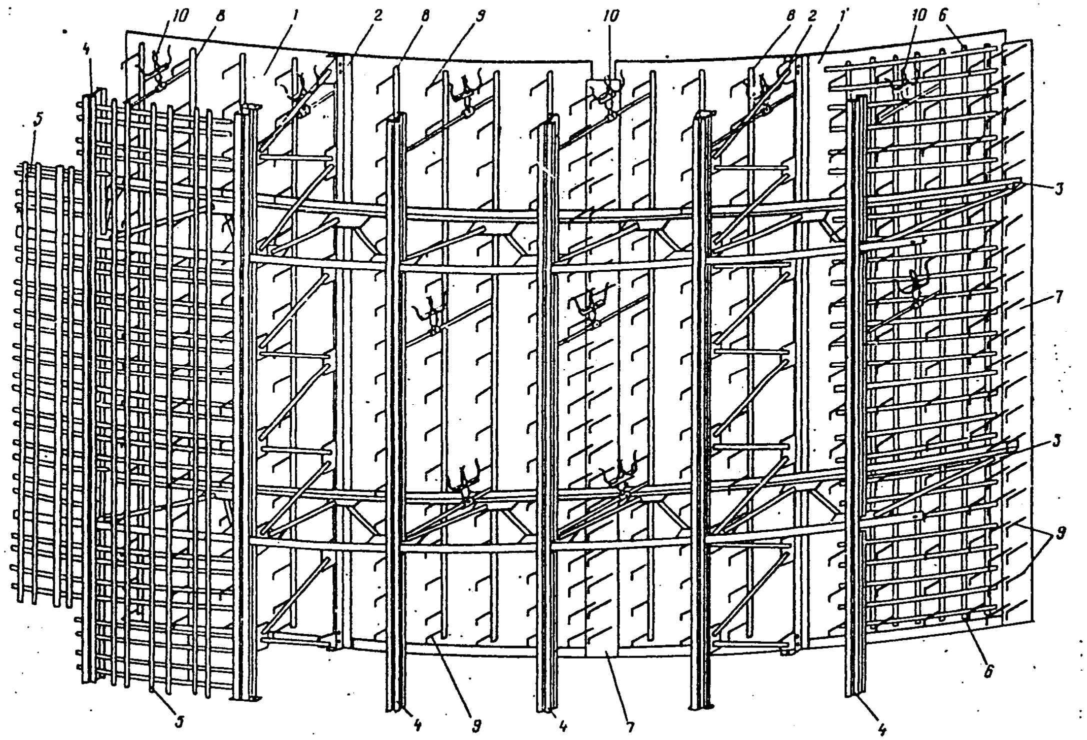
[1] Two electric motors of 2.2 kilowatts each, 1450 rpm, three-phase, 380 volts, 50 hertz are installed on the pump.



Fragment of the joining of the modules of the cylindrical part of the shell

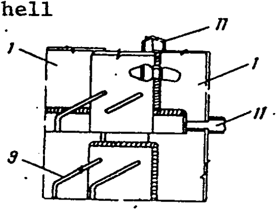


Figure 5. Three-dimensional reinforcing module of the cylindrical part of the shell. 1 -- sealing lining made of sheet steel; 2, 3 -- horizontal and vertical stiffening girders; 4 -- guides for the sliding forms; 5, 6 -- outside and inside reinforcing grids; 7 -- cover plate; 8 -- angle for fastening the anchor rods; 9 -- anchor rods; 10 -- clamps for fastening the channel former; 11 -- batten for monitoring the tightness of the installation welds.

smoke stacks) and other areas of the national economy (for prestressing bridge structures, television towers, oil and gas tanks). As experience shows, the basic elements of the powerful prestressing systems (reinforcing cables, anchors, and so on), can be used widely when erecting the long-span guying structures.

Manufacturing Process for Powerful Stressed Elements Using the Continuous Coiling Method[1]

The adopted structural design of the shell has required the use of stressed reinforcing elements (bunches) of significant length (up to 108 meters) with very high tensile force (10,000 kN).

The tension of the stressed reinforcing elements to 10,000 kN has permitted not only simplification of their geometric distribution in the body of the stressed structure, but also a decrease in the number of reinforcing bunches, the anchors and also the volumes of operations with respect to their installation and stressing.

The tests of the powerful reinforcing bunches of different structure have demonstrated that the least losses to friction in the curvilinear channel formers are observed when using bunches made up of parallel smooth wires. It has also been established that the basic process deficiency of the powerful bunches made up of individual sections of the wires or strands is complexity of anchoring them. For bunches made up of parallel wires with upset heads, the labor consumption of assembling the plate type anchors required for locking the bunches is extraordinarily high. Taking this into account, the decision was made to use two-loop reinforcing bunches made of smooth high-strength wire 5 mm in diameter according to All Union State Standard 7348-63 by the continuous coiling method. The basic advantage of the two-loop reinforcing bunches consists in the possibility of mechanizing the process of anchoring them.

It was necessary to solve the technical problems connected with the manufacture of elements of different length (from 40 to 108 meters), the release of the bunches from the tension (700-800 kN) occurring during the coiling process, for removal of them from the stops on the process line and coiling into portable coils, and so on.

For the manufacture of reinforcing elements by the method of continuous coiling, the Orgenergostroy Institute has developed a special process line. This line is installed in the industrial zone of the Novovoronezh Nuclear Power Plant. It consists of storehouses of high-strength wire, auxiliary materials (gun lubricant, tie wire, and so on) and finished products; the stations for rewinding the high-strength wire from the coils delivered by the plant onto drums with a capacity of up to 2 tons, winding it on the stops, winding it into coils and hot lubrication of the finished

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[1] This section of the article was written by Candidate of Technical Sciences Yu. G. Khayutin, engineers R. K. Kozochkin, A. Z. Krichevskiy.

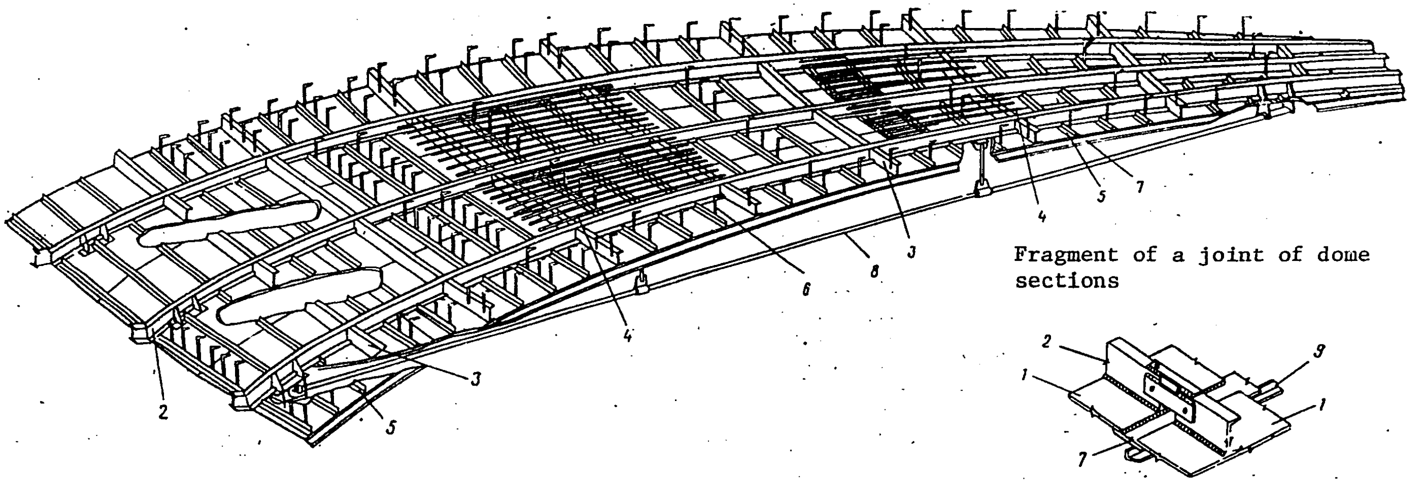

Figure 6. Metal frame dome section. 1 -- sealing lining made of sheet steel; 2, 3 -- radial and annular stiffening ribs; 4 -- reinforcing rod; 5 -- angle for fastening the anchor rod; 6 -- anchor rod; 7 -- cover plate; 8 -- tie bar; 9 -- batten for monitoring density of the installation welds.

reinforcing elements and also placement for equipment repair. The high-strength wire storage is an open area with a 400 m^2 concrete foundation. On the site there is a 2,5 m^3 tank for spent oil used for anticorrosion lubricant of the wire coils. The lubricated wire is stored on wooden pallets laid on the concrete base. The transportation of the wire from the storage to the rewinding station is by monorail equipped with a 1000 kg electric hoist.

For rewinding the wire from the coils onto the drums, a device has been designed and manufactured which is equipped with a drive coil holder with a brake and laying mechanism.

In connection with the fact that the weight of the delivered coils is 400 to 500 kg (which is 10 to 15 times less than the weight of the bunch), the wire is spliced with lapping and winding of the joint with tie wire. For these purposes, a manual mechanism was used which was designed by the VNIIST Institute and was used earlier for splicing wire when winding on the prestressed reinforced concrete tanks.

The reinforcing elements were made by winding the wire on end stops installed on the reinforced concrete foundation 142 meters long and 4.5 meters wide. A rail track was mounted on the same foundation for moving the basic process equipment -- the reinforcing-winding and unwinding machines. One of the end stops is designed for rough adjustment of the length of the manufactured bunches within the limits of the entire range of the required lengths of the stressed elements. Another, moving stop is used for exact adjustment of the length of the manufactured bunches (within the limits of ±5 cm) and also for taking stress off the stops on completion of coiling of the wire. For this purpose the moving stop can be shifted by power hydraulic cylinders along the longitudinal axis of the foundation. Two brackets are installed on each of the stops to which the thimble of the tension anchors or the inserts of the leading fittings are attached.

The two-spindle ANM-1 reinforcing winding machine developed and manufactured by the Solnechnogorskiy experimental complex is moved on rails using a cable drive. On the running platform of the machine two supporting and rotating devices are installed, each of which is equipped by one single-arm spindle and bracket for installing two drums with high-strength wire. The drums are equipped with brakes. The position of the spindles can be adjusted with respect to height, thus insuring the given order of laying the wire on the stops. In one pass between the stops in both directions the machine lays eight wires with a tension of 1500 to 2000 N each. Two reinforcing elements are wound simultaneously.

The bending of the stops by the spindles is insured as a result of unwinding the supporting and rotating devices by 180°. Simultaneously, the drums with the wire are unwound by the same angle. This prevents twisting of the wire along the spindle axis and insures the unstressed state of the rectilinear bundle after release of it from the stops.

Figure 7. Basic elements of the prestressing system with calculated tensile force of the reinforcing cables of 10,000 kN. 1 -- two-loop bunch of 450 high-strength wires; 2 -- thimble of the tension anchor; 3 -- threaded sleeve; 4 -- locking nut; 5 -- anchor block; 6 -- channel former; 7 -- distributing bushing; 8 -- regular insert of the blind anchor; 9 -- leading adaptor; 10 -- temporary insert; 11 -- locks.

After completion of the winding of the bunches, the loop sections are fastened using clamps on the thimbles, and the fairings of the leaders are pressed. Then the moving stops are shifted by the hydraulic cylinders along the direction of the adjustable attachments; here the bundles are unloaded.

The next operation is installation wrapping of the bundle with a soft wire with a spacing of 1,5-2 cm. For extablishment of the lays, the bunches are raised in individual sections by a boom crane with a capacity of 10 tons using a sliding loop. After setting up the lays, the ends of the finished bunch are removed from the stops. The winding of the finished reinforcing elements into coils is realized by a special machine with a drive conical coil holder installed by means of a supporting-rotating disc on the running platform. For ordering the lays in the coils of elastic reinforcing element about 130 mm in diameter, a horizonal laying drum which adjusts the height of the lays of the turns of the bunch, is mounted on special lifting brackets. The height of the unwinding drum is adjusted by hydraulic cylinders. A drive pump and its drive are mounted inside the coil holder. The running wheels of the platform are not drive wheels, but they are equipped with brakes.

For winding the finished reinforcing element into a coil, one end is picked up by the crane and attached to the coil holder; the other end is fastened to the stop. By turning the coil holder during braking of the wheels on the running platform, the coiling of the element into a tight coil 3.4-3.5 meters in diameter and weighing up to 8 tons is realized. The coil is fashioned by lays of 4 and 6 turns 8 to 10 mm in diameter and it is removed from the coil holder by the 10-ton boom crane.

The station for hot lubrication of the reinforcing elements is made up of a reinforced concrete basin 4 meters in diameter and 3.5 meters deep with inside steel lining and steam registers and also a flat tank. The coil of reinforcing element is submerged by the boom crane for 20 minutes in the pool with the heated gun oil, then it is raised above the pool and left for 10 or 15 minutes until the oil cools. Then the coil is lowered on the bottom of the flat tank where it finally cools in 1 hour, and it is sent to the finished production warehouse, which is an open area with a concrete platform 200 to 220 m^2. The coils are installed on wooden pallets in two tiers. The gun oil in barrels is also stored on this platform.

The process line for the manufacture of the reinforcing elements is serviced by a brigade of 18 people (6 people per shift). Two men worked at the station for rewinding the wire off the coils onto the drum. Three workers wound the reinforcing elements. One of them performed auxiliary operations (splicing the wire, moving the drums after winding, and so on). On completion of winding of the wire on the stops, he together with the members of the team servicing the winding machine pressed the leading tip, bound the bunch, wound it into coils and lubricated it. This arrangement offered the possibility for the brigade to manufacture 13 to 15 tons of reinforcing elements every 24 hours.

Hereafter, the production of the bunches must be organized in a closed, heated facility equipped with 10 ton bridge cranes, which offers the possibility of operating the process line around the clock at full capacity. The application of the developed and presently manufactured modified process line machinery will permit approximately a 50% increase in its output capacity and a reduction in labor consumption of the basic process operations. This will permit satisfaction of the demands for stressed elements of all of the nuclear power plants with the VVER-1000 power units which are to be built in the next decade.

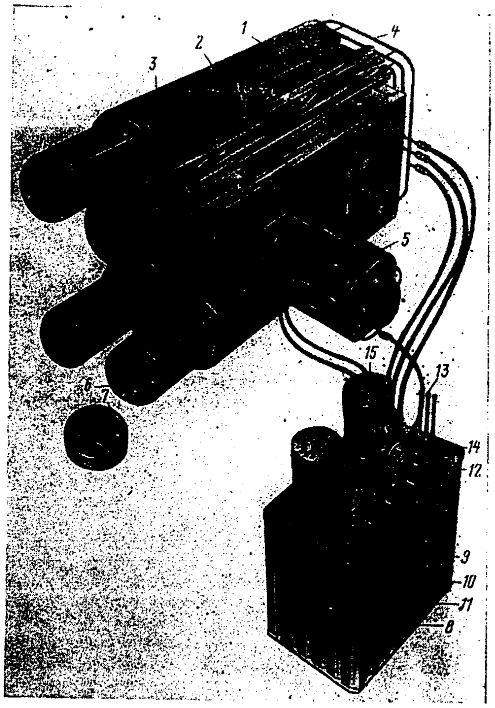

Figure 8. Hydraulic jack and pump for prestressing reinforcing cables with a force of 10,000 kN. 1, 3 -- first and second pressure chambers respectively; 2 -- return chamber; 4 -- manifold; 5 -- mechanism for advancing the connecting ring; 6 -- ball support; 7 -- supporting plate; 8, 9 -- high and low pressure pumps respectively; 10 -- filter; 11 -- oil tank; 12 -- high pressure valve; 13 -- low pressure distributor; 14 -- pressure gages; 15 -- electric motor.

Experience in Building the First Prestressed Protective Shell[1]

The basic design solutions for the Soviet protective shell correspond to the most advanced areas of construction of such shells in world practice.

The process of erecting the protective shell was developed considering the advanced experience of the power engineering and industrial construction

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[1] This section of the article was written by Candidate of Technical Sciences Yu. G. Khayutin, engineers D. V. Prozorovskiy, I. S. Vinogradov, A. Z. Krichevskiy and R. K. Kozochkin.

Figure 9. Prestressing two-loop reinforcing cables installed in the dome of the protective shell.

accumulated in the USSR, the technological possibilities and organizational structure of the construction and industrial enterprises of the branch [6].

When building the protective shell of the fifth power unit of the Novovoronezh Nuclear Power Plant, it was necessary to master a number of theoretically new technological processes. Accordingly, it was necessary for the design organizations and enterprises of the USSR Ministry of Power Engineering to manufacture and test special process equipment in the shortest possible time for the all-around mechanization of the operations of erection, prestressing and servicing of the protective shell during its operation and maintenance.

In 1971-1973, by assignment of the master planner, the Orgenergostroy Institute developed a process for erecting the protective shell of the pilot power unit [1] and also the technical specifications for the nonstandard equipment required for this, including the prestressing system. Provision was made for the following sequence of performing the operations:

Advance installation of the supporting reinforcing frame made of large three-dimensional modules including the external and internal reinforcing grids, steellining, horizontal and vertical girders made of shaped rolled products;

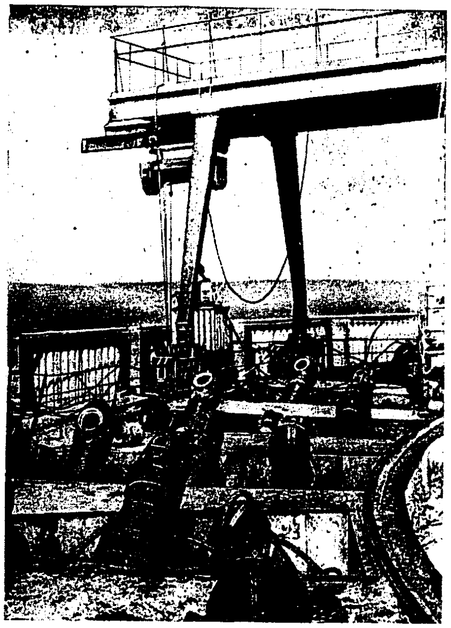

Figure 10. Anchors of the helicoidal reinforcing on the upper cornice of the shell.

Pouring the vertical walls of the shell in a one-way sliding form to the 55.0 meter mark;

Installation of the 400 ton polar bridge crane;

Installation of the reinforcing frame of the vertical walls and the upper cornice of the shell and pouring them to an elevation of 70.0 meters;

Installation of sectional reinforced form modules of the dome resting on a temporary girder;

Installation of channel formers and the routine reinforcing of the dome;

Pouring the dome;

The manufacture of stressed reinforcing elements and anchors;

Installation of reinforcing elements and anchoring them on the structure;

Prestressing of the protective shell and preservation of the prestressing system:

Testing the protective shell with inside pressure.

The three-dimensional reinforcing modules of the supporting frame of the vertical walls of the shell were made in the territory of the industrial zone of the Construction Administration. The reinforcing modules of the shell frame 9.7 × 6.7 × 1.2 meters in size included flat reinforcing grids, transverse girders, guides for the sliding form and also the internal sealing lining. The elements of the three-dimensional reinforcing modules were manufactured using individual patterns, and then they were assembled in jigs. The control assembly of the reinforcing modules of the cylindrical part of the shell was carried out on a vertical sectional stand. The reinforcing modules were transported in the horizontal position on a special trailer designed for hauling oversized loads. A separate process station was set up to manufacture the polyethylene channel formers. The simplicity of performing the process operations with respect to bending and joining the channel formers, the small weight of their installation sections permitted significant facilitation of the performance of the operations (by comparison with the operations of laying the steel channel formers) [5]. In addition, the application of the channel formers made of polymer tubes offered the possibility of reducing the steel consumption for construction by 1000 tons. However, when using polyethylene channel formers the possibility of their being burned when the incandescent slag hits them during the welding operations is not excluded. In order to prevent this danger it is necessary to use tubes made of noncombustible polymer materials or a metal sleeve of limited flexibility. (The last-mentioned channel formers are appreciably cheaper than the polymer tubing of the corresponding diameter).

The most labor consuming operation when erecting the reinforcing frame of the shell is joining the adjacent reinforcing modules. For each reinforcing module it is necessary to join 80 rods 32 mm in diameter by pool welding. In order to reduce the expenditures of labor on joining the reinforcing rods, it was proposed that the ends of the reinforcing grids be welded to the steel strip framing the reinforcing module around its perimeter. However, this solution increased the metal consumption somewhat as a result of introduction of additional framing of the reinforcing modules. Hereafter, the joining of the rod reinforcing of the grids by clamping bushings may turn out to be more efficient. The introduction of this process requires improvement of the existing clamping mechanisms and, the main thing, increased accuracy of manufacturing the three-dimensional reinforcing modules. The equipment for welding, assembly and adjustment of the three-dimensional reinforcing modules during the installation process can make it possible to designate strict tolerances with respect to coaxialness of the joined rods for installation of the clamping bushings.

In order to reduce the number of installation units of the shell and, consequently, the volumes of operations with respect to joining the reinforcing, it is necessary to adjust the centralized manufacture of the portable three-dimensional reinforcing modules of the frame and consolidate them before installation. In the construction of the fifth power unit the dimensions of the reinforcing modules were determined to a significant degree by the arrangement, the load capacity and the number of available cranes. Thus, as a result of the insufficient lifting capacity of the BK-1000 crane with the boom fully out, the individual reinforcing modules of the frame had to be installed without the internal sealing lining. At the same time, on the order of a production experiment in the section of the shell closest to the crane a double three-dimensional reinforcing module 13.4 × 9.5 meters in size was installed. It must be noted that this increase in height of the reinforcing modules cannot be considered optimal, for in this case the number of joints of the channel formers increased sharply, and it became more difficult to align them axially during joining. Hereafter, it is expedient to increase the installation dimensions of the reinforcing modules only horizontally, maintaining their height within the limits of 6-6.5 meters.

The next problem connected with the installation of the three-dimensional reinforcing frame of the shell has more an organizational than technical nature. It consists in preventing burning of the lining destroying the seal of the structure which can occur during the welding process.

The cylindrical shape of the protective shell permits one of the most efficient methods of forming concrete to be used -- in a sliding form. With appropriate organization of the operations and insurance of uninterrupted feed of the concrete mix, the concrete pouring rate can exceed 3 m/day [7].

The structure of the sliding form designed by the Orgenergostroy was worked out on fragments of the shell installed in the industrial zone of the Novovoronezh Nuclear Power Plant. The concreting conditions were established there which insured good quality of the concrete surface.

Considering the possibility of operation and maintenance of the form in the lifting-adjustment mode, the center elements of the form were reinforced, which naturally led to some increase in its weight. However, the construction experience has demonstrated the expediency of this solution since for various organizational-technical reasons the lifting-adjustment regime of movement of the form has turned out to be basic.

For vertical and horizontal transporting of the concrete mix when erecting the shell, a system of six concrete lifters installed around the outside perimeter of the shell at an equal distance from each other, 12 dump buckets moving along a monorail on the sliding frame and also transfer devices and guide troughs has been developed. Later, a concrete pump transport system was developed using a tower-boom crane installed in the center of the reactor division as the concrete guide manipulator, but the indicated systems were not ready in time. Concrete pumps and power cranes were used to pour the structures of the protective shell, walls and the floors and ceilings of the inside structural elements. The walls of the shell to the 22.0 meter mark were poured using the concrete guide manipulator installed together with the concrete pump on the KrAZ-257 truck chassis; for pouring the inside structures, including the floor at the 22.0 meter level, the end element of the manipulator was connected to a stationary concrete guide. The stationary concrete guides were connected to the concrete pump, bypassing the manipulator. This made it possible to feed the mix through three vertical stand pipes mounted around the perimeter of the shell to the 56.0 meter mark. However, it was necessary to provide for increased mobility of the pumped mix to do this. The most of the concrete above the 56.0 meter mark was poured using a crane.

Mechanization of the operations of installing the reinforcing bunches weighing up to 8 tons and more than 100 meters long and also the anchor attachments on the structures was of defined complexity. For unwinding the coil with the finished bunch and feeding it to the channel former, a special machine was built. The installation of all the reinforcing bunches (a total weight of 1620 tons) was accomplished using one modified machine (before the modification the plan called for using two like machines).

For installation of the anchors in the openings in the mounting parts, some fittings were manufactured which were mounted on self-propelled manipulators. In connection with the fact that the manipulators were initially designed only to move hydraulic jacks, changes were introduced into their design providing for the possibility of working with interchangeable equipment. Subsequently, mechanisms for installing tension eyes and inserts of blind anchors were used as the interchangeable equipment of the manipulators. Electric winches for tightening the reinforcing bunches in the channel formers were also installed on the dome manipulators. The manipulators were moved by hydraulic jacks around the annular rail tracks of the upper and lower tunnels and the dome arranged along the anchoring zones around the entire perimeter of the protective shell. Special mechanisms with which the manipulators were equipped provided for translational movement and rotation of the hydraulic jacks in three planes, which is necessary for approaching the tension anchors, removal of the jack after tension and its movement to the next anchor.

During the process of the experimental operation, the structure of the upper and also the dome and lower manipulators was altered. The performed modifications made it possible to increase the output capacity of the manipulators and decrease their number by 1.5 to 2 times, simultaneously reducing the number of service personnel and the times required to perform the operation.

The prestressing of the reinforcing cables was realized by four-cylinder hydraulic jacks developing a tractive force of 10,000 kN with a pressure of the working fluid in the hydraulic system of 34 MPa. The hydraulic jacks were used together with the high-head submersible pumps. The prestressing of the reinforcing elements was carried out after the concrete reached the calculated strength and stretching the reinforcing elements under a tension of 800 to 1000 kN with installation of them to decrease the idle stroke of the hydraulic jacks during prestressing.

Before the beginning of tension, the manipulator with the hydraulic jack in the transport position and the pump were brought up to the tension anchor, then by lifting the manipulator guides and correcting the movements the hydraulic jack was installed coaxially with the reinforcing element and moved up to its thimble until the transverse through openings in the hydraulic jack housing and the thimble lined up. Then the connecting pin was pressed by special mechanism and the reinforcing element was put under tension by the hydraulic jack. On completion of drawing up the reinforcing cable and tightening the lock nut against the supporting plate, the pressure in the hydraulic system was released, the plungers of the hydraulic jack were retracted, the connecting pin was pressed out and the pressing mechanism was moved along the housing of the hydraulic jack. Then the manipulator guides were lowered to the extreme lower position, the tension equipment was moved to the next tension anchor, and the operations were repeated in the above indicated order.

The prestressing forces of the reinforcing cables when putting them under tension were measured by the pressure of the working fluid in the hydraulic system; the forces on the blind anchors were measured during the tension and the operating process by using annular tensometric dynamometers installed selectively on each twentieth stay. After putting tension on 30% of the dome reinforcing bunches to a force of 6000 kN, the dome and wall reinforcing above and below the shell was put under tension to 10,000 kN.

With simultaneous operation (in two shifts) of five hydraulic jacks, each of which was serviced by a crew of four, 10 to 12 cables were put under tension every 24 hours (maximum output capacity, 14 cables per day with two shift operations). This organization of the operations made it possible to prestress the shell in two months.

The experience obtained when building the Novovoronezh Nuclear Power Plant served as a prerequisite for significant modification of the anchors and the hydraulic jacks providing for a reduction of their weight and size by 25 to 30%, an increase in their technological nature and reliability and also the development of accelerated methods of installation and prestressing of all of the reinforcing cables from the upper cornice.

During erection of the protective shell of the pilot power unit with VVER-1000 reactor, the process for the manufacture and installation of the metal structural elements and the basic elements of the prestressing system and also pouring the concrete structures were assimilated, the nonstandard process equipment was developed, a production base was created for centralized manufacture of the structural elements and assemblies, and highly qualified specialists were trained to perform the new technological processes and operations.

The experience in building the protective shells for the fifth power unit of the Novovoronezh Nuclear Power Plant confirmed the high technological nature of the construction and the fitness of the developed systems and mechanisms and also the possibility of further reduction of the labor consumption and reduction of the construction times.

BIBLIOGRAPHY

1. Yu. G. Khayutin, A. Z. Krichevskiy, A. K. Belyanichev, "Structural-Process Problems of Erecting the Protective Shells of Nuclear Power Plants," ENERGETICHESKOYE STROITEL'STVO (Power Engineering Construction), No 10, 1974, pp 22-27.

2. A. P. Kirillov, Yu. G. Khayutin, A. Z. Krichevskiy, et al., "Prerequisites for Selecting the Diagonal Method of Reinforcing the Protective Shell of the Fifth Unit of the Novovoronezh Nuclear Power Plant," TRUDY GIDROPROYEKTA (Works of the Hydraulic Design Institute), No 41, 1975, pp 128-139.

3. A. Z. Krichevskiy, "Study of the System for Prestressing the Protective Shells of Nuclear Power Plants," ENERGETICHESKOYE STROITEL'STVO, No 4, 1976, pp 18-23.

4. Yu. V. Ponomarev, R. K. Kozochkin, Yu. G. Kayutin, et al., "Manufacture and Testing of Powerful Reinforcing Bunches for Stressing the Reinforced Concrete Shells of Nuclear Power Plants," ENERGETICHESKOYE STROITEL'STVO, No 5, 1976, pp 24-28.

5. Yu. G. Khayutin, V. A. Dorokhin, R. K. Kozochkin, et al., "Polyethylene Channel Formers in Protective Shells of Nuclear Power Plants," ENERGETICHESKOYE STROITEL'STVO, No 7, 1977, pp 27-31.

6. A. Z. Kricheskiy, Yu. G. Khayutin, METODY VOZVEDENIYA ZASHCHITNYKH OBOLOCHEK AES S VODO-VODYANYMI REAKTORAMI (Methods of Erecting the Protective Shells of Nuclear Power Plants with Water-Cooled, Water-Moderated Reactors), Moscow, Informenergo, 1973, 36 pages.

7. Yu. G. Khayutin, V. A. Dorokhin, R. K. Kozochkin, et al., "Sliding Form for Pouring the Concrete of Protective Shells for Nuclear Power Plants," ENERGETICHESKOYE STROITEL'STVO, No 5, 1977, pp 19-24.

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FUELS

UDC 620.9:338.9

FORECASTING DEVELOPMENT OF FUEL-ENERGY COMPLEX IN USSR

Moscow IZVESTIYA AKADEMII NAUK SSSR. ENERGETIKA I TRANSPORT in Russian No 3, May-Jun 80 pp 21-30

[Article by A. A. Makarov]

[Text] The systems approach to long-term forecasting of development of the fuel-energy complex is characterized.* A system of mathematical models realizing it, which includes models of the development of the economics, energy demand, exploration and exploitation of the organic fuel basins and the model of strategies for development of power engineering, is described. The most significant results achieved in practical use of the system of models are considered.

Study of the future structure of the fuel-energy complex (TEK) is one of the important trends of system investigations of power engineering having their own special methodological and content problems. Three steps in study of the prospects for development of power engineering can be distinguished by the content of the problems being solved, organization and methods of investigations: future planning for a period up to 10 years, medium-term (from 10 to 15-20 years) and long-term (up to 30-40 years) forecasting. The systems approach to future planning of power engineering has been widely developed for many years and is being practically implemented in development of the subsystem "Fuel-energy complex" of the automated control system for planning calculations under Gosplan of the USSR [1] and the sector automated power engineering systems. The methods and results of applying the systems approach to medium-term forecasting of the development of power engineering have been outlined rather broadly in the

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*With respect to terminology, the concept "fuel-energy complex" coincides with the concept "power engineering" in its wide meaning which encompasses the entire aggregate from processes of production and refining energy resources to energy receivers, inclusively. Therefore, the terms "power engineering" and "fuel-energy complex" are regarded as synonyms in the article.

literature [2, 3]. The main results achieved in the field of systems investigations of long-term prospects for development of power engineering are characterized in the article.

Systems investigations of the future are a complicated creative process which requires the maximum use of the experience of intuition of specialists, supplemented by development of a specific combination of content methods, including formalized methods. According to this, one of the possible schemes of systems investigations of long-term development of power engineering is considered below and the main steps with illustration of the results of using the proposed models, methods and calculating procedures are considered in more detail.

Systems investigations of forecasting the development of power engineering are essentially systems-analytical investigations and include the study of the external relationships of power engineering to the national economy (economics) and the biosphere (we have in mind the mutual effect, including the ecological effect, of development of power engineering and the encompassing geophysical processes). The complex and intimate interdependence of many external and internal relationships of power engineering leads to the fact that the quality of forecasting can be improved significantly by using special mathematical models. The main purpose is qualitative description of the studied relationships, making multiversion calculations and simulating the possible consequences of one or another variation of initial conditions.

Teaching about the effect of the interrelated combination of objective progressive trends in development of power engineering occupies an important place in the considered investigations (see [2] for more detail). Study of the intensity of manifestation of these trends in the past, for example, during the past 30 years, and during the planned period, i.e., during the next 10 years, permits one to use them to estimate and check the possible conditions for development of power engineering for the predicted 15-20-year period and, which is important, assist one to select on a sound basis the best solutions on the development of power engineering from a large number of possible solutions.

The outlined scheme of long-term forecasting of TEK is directed toward solution of the following main problems:

1) selection of the most effective trends of scientific and technical progress in the TEK for corresponding distribution of the means for investigation and development;

2) determination of the required deadlines for development of fields and the scope of fuel production under extreme conditions (remote regions with unfavorable geological or severe climatic conditions, off-shore shelves and so on) for preparation of the required technologies and development of the infrastructure in regions of new development;

3) estimation of the required intensity of energy-conservation policy for preparation of the appropriate technologies, restructuring of state standards and norms and if necessary of the sector and territorial structure of the economy.

A thoroughly developed system of methods and models of forecasting various aspects of TEK development ensures solution of the enumerated problems.

It has now been determined that at least consolidated modelling of the development of TEK economy is required for well-founded forecasting of TEK development, in addition to the developments of several initial hypotheses for development of the national economy. First, this will permit determination of the corollation, important for forecasting TEK development, between the needs of the national economy for available energy and its real capabilities of allocating the necessary funds for development of power engineering.* Second, one can take into account the inverse effect of the strategies of TEK development on the economy under modern conditions of the significant growth of expenditures for fuel only by multivariant modelling of development of the economy.

An inseparable part of systems investigations of TEK development is forecasting energy consumption and methods of producing available energy. But the problem is according to which cross section of the energy conversion chain future estimates of energy consumption will be most reliable. Our forecasts were practically made until recently at the level of the converted forms of energy: electric power, steam and hot water and also liquid, gaseous and solid fuels. An important sphere of the interchangeability of converted forms of energy and fuel, dependent on methods of producing them and the expenditures corresponding to them, was thereby excluded from systems analysis. At the same time this analysis contributes under modern conditions to acceleration of the readjustment of the production structure of power engineering, specifically, by replacing liquid fuel by other energy resources. Therefore, in the methodical sense it is more correct to make a long-term forecast of energy consumption, orienting oneself to consumption of so-called available energy used directly in production, transport and domestic processes, in the national economy.

Production of resources is also a traditional component of energy forecasting. A comparatively new element which has become widespread with conversion to methods of systems analysis is forecasting not only the size of fuel resources but also their cost distribution. It was this that made it possible to formulate the problem of optimization of the TEK production structure. In the general case forecasting the resources should include an estimate of the expenditures for exploration of the predicted fuel resources (especially oil and gas) with determination of the geological characteristics of the reserves and expenditures for fuel production with determination

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* See L. A. Melent'yev's article in this issue on the concept of available energy.

of the rational dynamics of developing large fuel bases. The latter is naturally related closely to optimization of the TEK production structure.

An important component of investigating the prospects for development of power engineering is predicting scientific and technical progress. There is no doubt that it must be taken into account when forecasting the TEK, but this is largely done in practice by being given hypotheses about the composition, deadlines for implementation and the technical-economic indicators of new technologies. Moreover, the systems approach requires direct consideration of the effect of the directions and conditions of development of power engineering on the rates and methods of scientific and technical progress. Study and modelling of the corresponding relationships is another problem of future investigations.

The TEK production structure itself is predictied on the basis of modelling its technological and territorial relationships and also existing and new technologies of production, conversion, distribution and utilization of fuel-energy resources. The main material, labor and monetary expenditures for development of TEK and also the ecological restrictions should be fully taken into account in this case, as well as the possibilities and conditions for export and import of energy and a number of other factors. The main blocks of the system of TEK forecasting models are characterized below.

Modelling the development of the economy and its relationships to development of the fuel-energy complex. The model of development of the economy, used in TEK forecasting, is an intersectorial dynamic model which describes the development of 26 sectors of the economy and which maximizes the growth rates of final public consumption (with regard to improvement of it structure) with restriction on the number of those engaged in the production sphere. It is constructed on the basis N. F. Shatilov's dynamic model [4] by introduction of sectors which support development of the TEK and of development of the so-called adaptive version of the model which considerably expands its capabilities as a forecasting tool. A detailed description of the model and the investigations carried out on its basis is given in [5].

Use of the proposed model is related to extensive information difficulties since it requires forecasting of up to 1,500 coefficients of the expense-production matrix. Attempts which we undertook to simplify the model of development of the economy by converting to a smaller number of sectors of the national economy (19 and 7 were considered) and moreover to a macroeconomic model of the production function type was unsuccessful: the model of the economy became insensitive to the changing conditions of TEK development and did not provide the remaining aspects of forecasting with the required information on development of the national economy. Therefore, special procedures were required to enhance the reliability of predicting the coefficients of the expense-production matrix.

The first of them consists in using not only the past, but also the future values of the coefficients developed during planning for 10 years in the future for the long-term prospects. As a result, accounting data for 1968 and planning indicators up to 1990 are now being used to predict the coefficients of the matrix of intersector relationships of the dynamic model of the economy. Based on this 22-year statistics, which also included part of the step of the changing conditions of power engineering development, one can determine with some justification the values of the coefficients for 10-15 years ahead. It is important in this case that the majority of the extrapolated indicators be mutually independent and that the effect of each of them on the rates and structure of economic growth be negligible; this permits one to calculate for mutual compensation of the errors.

Another approach consists in adapting the solution of the dynamic model to several macroindicators of long-term development of the economy: growth of national income and of the consumption and accumulation fund. These indicators should be determined in special economic forecasts made independently of energy forecasting. This adaptation is being implemented by a special method [5] by chaining the coefficients of the matrix of intersectorial relationships within the ambiguity of their values.

Investigating the model of development of the economy permits one to obtain the following information used to form and compared the strategies of TEK development:

1) the dynamics of the main indicators of development of the economy--the national income, capital investments, output of the main types of energy-consuming products required to predict the energy needs of the national economy; these indicators are determined directly during calculation on the model;

2) the dynamics of the coefficients required to compare the different types of material expenditures (raw material, equipment and so on) and also the labor resources to form a unified entire function for the model of strategies for development of power engineering. These coefficients are equivalent to objectively founded estimates and are determined from the adaptive model of the economy in the form of so-called coefficients of the Kalman filter. They are dimensionless values which indicate the extent to which the presently existing relations of prices to production change by the end of the period under consideration and depend directly on the growth rates of labor productivity and the efficiency of utilizing new technologies. These changes, which are difficult to predict, are obviously distinguished by the types of product, and very significantly as well. Thus, the prices for products of ferrous and nonferrous metallurgy increase 4-5-fold by the year 2000 in one of the calculations, whereas prices for products of energy machinebuilding increased only 1.1-1.3-fold.

An estimate of national economic consequences of various energy strategies on the model of development of the economy is of principle significance for forecasting the TEK. This estimate is achieved by reverse substitution into the model of development of the economy of the needs of the TEK for products of other sectors obtained in calculation of the strategies of its development.

Experimental calculations carried out in this manner showed that the danger of delaying the rates of economic growth on the part of power engineering cannot in principle be exaggerated under conditions of the USSR. Thus, the specific capital consumption of power engineering, increasing significantly during the future, and consequently the rapid growth of the volume of capital investments in TEK usually present the greatest danger. However, according to our calculations, in practice this may not alter the growth rates of the country's national income under specific conditions (for example, with a simultaneous reduction of the material consumption of production and public consumption.

However, one must especially stipulate the conditions under which power engineering will have a relatively weak inhibiting effect on the rates of economic growth. These results were obtained under assumption that free movement of capital investments and of material and labor resources to the TEK from other sectors of the national economy is possible. If one takes into account the objective restrictions on readjustment of the intersectorial structure (cost, for example, by the deadlines of erecting objects in power engineering and its supporting sectors, the time required for personnel retraining and so on) and the possible inadequate allocation of capital investments for development of the TEK, the conclusions from the analysis may not be as optimistic. It is understandable that those restrictions which are not caused by the objective technological inertia of the national economy must be removed through every effort.

Modelling the increase of energy consumption and development of fuel-energy resources. The basis for long-term forecasting of energy needs is the given information about development of the economy and the objective trends of energy consumption determined on the basis of retrospective analysis. The latter represent stable functions in variation of specific indicators of energy consumption (specific energy consumption, the energy needs of labor and of basic funds, the energy utilization factors and so on) and of the structural relationships, i.e., the fraction in the energy use of sectors of the national economy, the types of energy-consuming processes and so on. The main trends of energy use are qualitatively formulated in [2] and have partially received a rather reliable quantitative estimate up to the present [3].

From this viewpoint, the recently established fact of the constant nature (with accuracy to several percent) of specific energy consumption of the national economy in available energy is of important significance. The low variability of the specific consumption of available energy per unit of national income (in unified prices) during the last 20 years occurred not only in the USSR but in the United States as well, which may be regarded as an objective characteristic of development of productive forces.

A new trend--reduction of specific energy consumption of the national economy in available energy should be objectively added together during the future stage of development of power engineering, characterized by a sharp increase of the cost of the main types of organic fuel and the specific capital consumption for production of nontraditional energy resources. However, an estimate of its possible quantitative manifestations showed that even in the first two decades it would be difficult to achieve a sharp reduction of this indicator. The measures required for this--review of existing norms with regard to energy use, changing of technologies, improvement of the highway system and transport facilities, heat supply systems and so on--each in itself makes a comparatively low contribution to reduction of specific energy consumption, but requires extensive efforts and time to realize. As a result, according to our estimates, one can expect a reduction of the specific consumption of available energy by 5-7 percent in the best case during the first decade and by 15-20 percent over a period of 20 years. This will correspond in absolute expression to a reduction of consumption of energy resources by several hundred million tons of comparison fuel.

Another objective trend of energy consumption, effective almost universally for many decades, is a reduction of the specific energy consumption of the national economy in primary energy resources. If the consumption of available energy is constant, a reduction of the specific consumption of primary energy resources is achieved by a systematic increase of the energy utilization factor (k.p.i.)--it increased from 31 to 44 percent during the past 20 years (Figure 1). However, the growth rate of the k.p.i. during recent years slowed down significantly. Thus, whereas the saving of energy resources achieved by this comprised approximately 150 million tons of comparison fuel annually during the period 1961-1965, the saving exceeds only a little more than 100 million tons of comparison fuel annually during the current five-year plan with more than twice the increased volume of production of energy resources. This is explained by exhaustion of those methods of saving energy resources such as conversion of rail transport from steam traction to electric and diesel locomotives, increasing the steam parameters and increasing the unit output of groups of electric power plants, increasing the efficiency of all types of energy installations by using gas and mazut instead of coal and so on.

New methods of increasing the k.p.i. such as conversion of the motor fleet to diesel, active saving of all types of energy resources, more intensive use of secondary energy resources and so on must be found and realized in the future.

The joint effect of measures to reduce the specific consumption of available energy per unit of national income, to increase the k.p.i. and the organizational-structural improvement of energy use will, we feel, permit a saving of primary energy resources reaching approximately 50 percent of the required increase of producing them. In other words, with proper organization, an intensive energy-conserving policy can make an important contribution to supporting national economic needs (and with fewer expenditures) than development of any of the producing sectors of the TEK.

The problem of the future stage along with slowing of the quantitative growth of energy use is further structural improvement (Figure 2). The

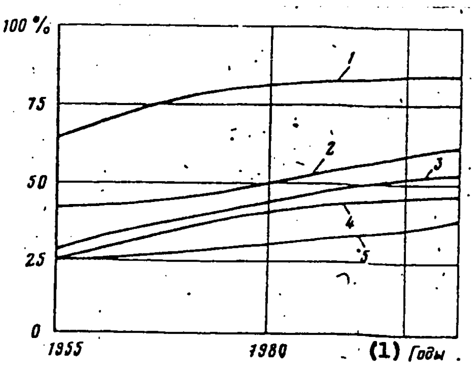

Figure 1. Dynamics of Utilization Factor of Energy Resources: 1--boilers and TETs; 2--industrial furnaces; 3--total k.p.i.; 4--thermoelectric power plants; 5--internal combustion engines

Key:
1. Years

leading link in this case as before will be accelerated electrification of the national economy: the fraction of electric power in meeting the available energy needs should be doubled over a period of 20 years and should reach 23-25 percent by the end of the century. Along with this, despite all measures to save liquid fuel, accelerated conversion of the national economy to motor transport should be and can be maintained.

It is important to emphasize that the named and other trends of energy use do not operate in isolation, but form a system of interrelated functions. This circumstance is also used in developing the mathematical models of energy use. There are different approaches to construction of these models. One of them is based on the use of the intersector model which describes the relationships between the development of the main sectors of the national economy and industry and their needs for available energy (with differentiation by processes), distribution by energy-consuming processes of main energy carriers and the capabilities of producing them with regard to consumption of products of the remaining sectors of the national economy for these purposes. The "expense-production" coefficients in this model are defined by ranges of values. Identification of their values in retrospect and forecasting future values (and as a result the levels and structure of energy use and the required production of energy carriers) are carried out by the criterion of the maximum k.p.i. (see [6] for more detail).

Another approach to modelling energy use provides statistical description of the developing trends of energy use in the form of a system of interrelated functions itself. Direct consideration of 15-20 sufficiently stable

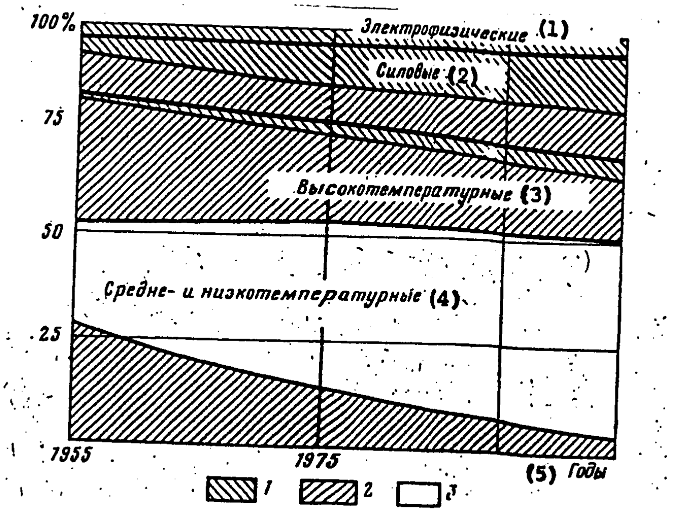

Figure 2. Structure of Available Energy Use By Processes and Their Support With Energy Carriers: 1--electric power; 2--direct fuel consumption; 3--steam and hot water

Key:

1. electrophysical
2. power
3. high-temperature
4. medium- and low-temperature
5. years

specific and structural indicators in the cross-correlation model which characterize different aspects of energy use permits one to find better-founded quantitative expressions for their past dynamics and to construct noncontradictory forecasts for the future. This model is now being debugged at the Institute of High Temperatures of the USSR Academy of Sciences.

Significant advances have been recently achieved in forecasting the dynamics of development of organic fuel resources, primarily of large oil- and gas-bearing provinces. Based on existing estimates of the predicted fuel resources in the considered region, the process of exploiting them to increase commercial reserves and to model the optimum priority and rates of development of proven reserves is being simultated to determine the rational dynamics of oil and gas production.

The model for simulating the process of exploration of a region by its structure and by the composition of the statistical functions used formalizes the known geological hypotheses, while the required numerical values of the parameters are simulated by the statistical testing method (the Monte-Carlo method) based on the experience of exploring the given and similar regions. The input information are the predicted fuel resources in the region and the number of future structures used in estimating them, while the predicted resources themselves can be refined by simulating the process of exploration. As a result, probable estimates of the increase of the commercial fuel reserves can be obtained (with division by the size of fields and the depth of their deposition) in the function of expenditures for exploration. The optimum dynamics of exploratory work, fuel production and maximum production expenditures in this region is determined from this information in the linear optimization model. The technical-economic indicators of exploiting various types of fields, functions of the effectiveness of bringing the fuel of a given region into the country's energy network and if necessary the restrictions on capital investments available for exploitation of a given region are used. It is obvious that the two latter groups of indicators can be found only as a result of optimizing the strategies of TEK development, which also determines the nature of the process of matching the forecasting of energy resources to the total forecast of power engineering development.

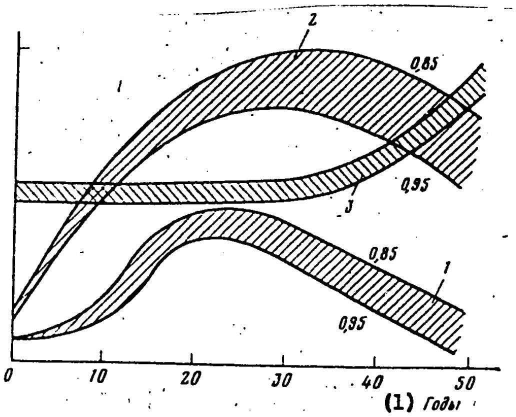

Figure 3. Dynamics of Main Indicators for Exploitation of an Oil- and Gas-Bearing Province (the upper lines are for a 0.85 level of support and the lower ones are for a 0.95 level): 1--commercial fuel reserves; 2--annual fuel production; 3--specific production expenditures (maximum)

Key:
1. Years

A number of important content results has been obtained by using the named models (a more detailed description of them is found in [7]). It is specifically shown that one can be oriented to conversion of only approximately half the predicted oil and gas reserves to commercial reserves with high probability (more than 0.8) at an acceptable level of expenditures. An important result is also the principle of variation of specific expenditures for fuel production during exploitation of a region, established by multivariant calculations (Figure 3). It consists in the following: the specific fuel production expenditures in the worth of the fields being exploited remain practically unchanged over the entire growth period of fuel production in the region and begin to increase (moreover, ever more intensively) only when the region enters the decreasing production phase. This principle has been confirmed in variation of the predicted fuel resources and with different volumes of capital investments in fuel exploration and production, although the level of ideal expenditures themselves are considerably dependent on the named factors. Discovery of this behavior of specific expenditures on fuel is of significant value for predicting the final expenditures and prices for fuel and energy.

Modelling the strategies for development of the fuel-energy complex. Forecasts of development of the economy, energy use and the dynamics of development of energy resources are used in working out the strategies for development of the TEK, study of the trends and rates of readjustment of its sector and territorial structure. The tool for variant investigation of these strategies is the dynamic optimization model of the TEK, which describes the interaction of available production technologies and those being developed, conversion and use of all types of fuel and energy in territorial profile (for the four zones of the country). Along with this, the restrictions on the scope of using the seven types of products of other sectors of the national economy in the TEK (ferrous and nonferrous metallurgy, the four machine-building sectors and the construction materials industry) and also the restriction on labor resources are depicted in the model. Development of the TEK is depicted in the model by five-year periods. The criterion of optimality is the minimum discounted expenditures for development of the TEK as a whole during the considered period, corrected for the anticipated variation of prices determined from calculations of the model of the economy.

Multivariant investigations based on the system of models and extensive heuristic analysis revealed the following main trends in development of the TEK production structure (Figure 4). The most acute problem of the future stage of TEK development will be to meet the needs of our country and to a significant degree the CEMA countries for liquid fuel. Study of this problem yielded a very important result: there is the principle possibility of providing these needs even with stabilization of liquid fuel production from the end of the 1980s. However, realization of this possibility would require rather urgent and large-scale measures such as conversion of the motor fleet to diesel fuel, a sharp increase in the extent of oil refining, industrial production of synthetic fuel from coal and shales by the end of the century, acceleration of electrification of transport facilities and also of a significant part of construction and agricultural machinery and mechanisms.

Intensive substitution of liquid fuel, primarily from the balance of electric power plants and boiler rooms, requires compensation for it by other

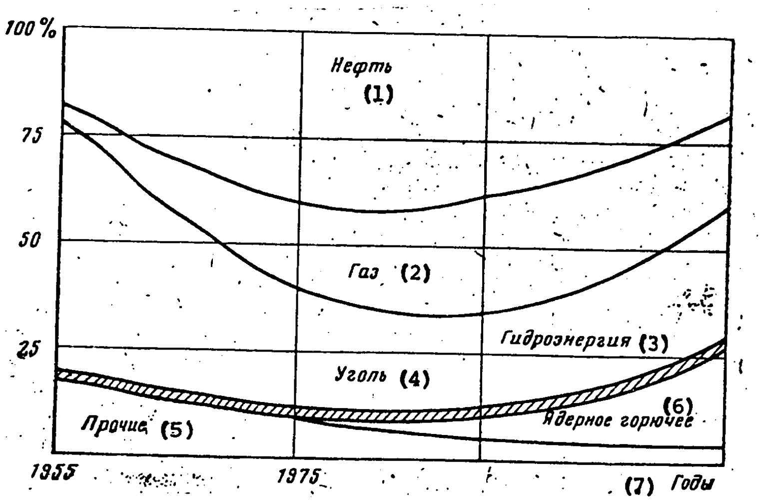

Figure 4. Structure of Primary Energy Resrouce Production

Key:

1. Oil	5. Miscellaneous
2. Gas	6. Nuclear fuel
3. Hydroelectric energy	7. Years
4. Coal	

energy resources and primarily by natural gas. In this regard a rapid absolute and relative increase of natural gas production is required before the end of the century and the bases for stabilizing it may appear during the subsequent period. The latter will not mean a reduction of efforts to develop the gas industry since the reduction of gas production at such giant areas as the Arctic and Urengoy fields and others must be compensated for during this period.

These trends in development of the oil and gas industry will result during the next decade in further growth of the fraction of hydrocarbon fuel in the country's energy balance with subsequent reduction of it. It is important to emphasize that the latter will be determined not by exhaustion of natural resources (considerably less than half the predicted hydrocarbon reserves will be consumed in the country over a 40-year period), but by more efficient use of the funds which the national economy can allocate for development of power engineering.

The most rapidly increasing element of power engineering in the future will be nuclear power engineering. Its fraction in the total production of fuel-energy resources may exceed 10 percent [3] by the end of this century and will double during the next 15-20 years provided that there is mass use of nuclear energy not only to produce electric power but also heat (atomic

TETs and boiler plants) where it yields the greatest national economic effect.

With regard to the foregoing, the fraction of the coal industry during the future will obviously be somewhat further reduced and will then become stabilized at the level of 22-23 percent up to the end of the 20th century. An increase of the fraction of coal in the total production of energy resources is almost inevitable during the subsequent period (bearing in mind electric power transmission from the eastern to the European regions of the country and organization of production of synthetic liquid fuel).

The territorial relationships of the TEK during the future period will be characterized by a rapid increase of flows of all types of energy resources from the eastern regions, mainly from Siberia. However, even during the last decade of the century, the absolute increase of fuel flows will vary significantly. It is especially important that the peak of the required import of Kuznetsk energy coal, which creates special stress on the Trans-Siberian Mainline Railways, to the European part of the country will apparently be passed by the end of the 1980s. The necessary condition for this will be construction of DC electric power transmission to the European regions from the Kansk-Achinsk electric power plants and the Siberian GES.

It is important to emphasize that the planned methods of development of power engineering cannot be accomplished without intensive scientific and technical progress. Such measures as development of atomic power engineering, intensification of petroleum extraction from beds, new types of gas transport and of electric power transmission from eastern regions, deep conversion of coal (including gasification) and so on will obviously provide almost one-fourth of the total production of fuel-energy resources at the level of the year 2000 or more than half the required increase of producing them. At the same time scientific and technical progress will contribute to using the requirements on the part of the TEK on the national economy although it may not completely compensate for the objective deterioration of the conditions of power engineering development.

On the whole, the given analysis of the long-term process for development of power engineering indicates that there are real capabilities of totally meeting the country's energy needs on the basis of our own resources without any appreciable delay of the rates of national economic development on the part of the TEK. The problem consists in detailed development of specific methods of realizing these capabilities.

BIBLIOGRAPHY

1. "Voprosy sozdaniya ASPR" [Automated Control System for Planning Calculations], Izd-vo GVTs of Gosplan of the USSR, 1976.

2. Melent'yev, L. A., "Sistemnyye issledovaniya v energetike" [Systems Investigations in Power Engineering], Nauka, 1979.

3. Makarov, A. A. and A. G. Vigdorchik, "Toplivno-energeticheskiy kompleks" [The Fuel-Energy Complex], Nauka, 1979.

4. Shatilov, N. F. and M. A. Gershenzon, "Metodologicheskiye polozheniya po ispol'zovaniyu dinamicheskoy modeli mezhotraslevogo balansa v svodnom perspektivnom planirovanii" [Methodological Aspects on Using the Dynamic Model of the Intersector Balance in Future Summary Planning], Novosibirsk, Nauka, 1971.

5. "Ispol'zovaniye mezhotraslevykh modeley dlya dolgosrochnogo prognozirovaniya energetiki" [Using Intersector Models for Long-Term Forecasting of Power Engineering], Irkutsk, Izd-vo SEI SO AN SSSR, 1979.

6. Maksimenko, Yu. F. and L. S. Kuz'mina, "Modelling the Intersector Balance By Means of a Man-Machine System," All-Union Seminar 'Systems Analysis and Modelling of Socioeconomic Processes'," Rostov-na-Donu, 1979.

7. Golovin, A. G., V. I. Kitaygorodskiy and I. Ya. Faynshteyn, "Forecasting the Reserves and Optimization of the Long-Term Levels of Gas Production Within the Framework of the Fuel-Energy Complex," EKONOMIKA I MATEMATICHESKIYE METODY, Vol 15, No 5, 1979

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