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Fluorescence of Sea Water. Instruments and Research

907F0176A Minsk IZVESTIYA AKADEMII NAUK BELORUSSKOY SSR: SERIYA FIZIKO-MATEMATICHESKIKH NAUK in Russian No 6, Nov-Dec 89 pp 89-95

[Article by A. V. Ilyushonok, S. P. Katsevich, V. N. Knyukshto, M. Ya. Kostko, B. P. Primshits, and S. Yu. Sakovich, Physics Institute imeni B. I. Stepanov, AN BSSR; first paragraph is IZVESTIYA AKADEMII NAUK BELORUSSKOY SSR: SERIYA FIZIKO-MATEMATICHESKIKH NAUK abstract (verbatim text as published in English in source)]

[Text] The main principles of designing the submersible fluorimetrical devices are formulated, the possibility of in situ sea water luminescence measurements (intensities and spectra) is substantiated theoretically, useful metrological procedures are proposed, the designed submersible fluorimeters BF-1 and BF-2 and spectrofluorimeter SSR are described, some results produced by the above devices are reported.

The optics of the ocean is an intensively developing area of oceanography.[1,2] The luminescent method occupies an important place among hydrooptic methods of researching the ocean. Dissolved organic substances and phytoplankton chlorophyll are natural fluorescent components of sea water. Measurements of the luminescence intensity of phytoplankton chlorophyll permit express study of the laws governing the distribution of phytoplankton and determination of the concentration of chlorophyll.[3] Research on the spatiotemporal variability of the phytoplankton chlorophyll of dissolved organic substances plays an important role in studying the dynamics of the ocean's waters.[4] Spectral luminescence analysis is a convenient method for making a qualitative determination of the species composition of phytoplankton and the component makeup of dissolved organic substances.

Fluorimetric research of the ocean's waters is conducted both in tests and flow-through systems and under natural conditions. The physical and chemical properties of analyzed samples may vary significantly. In situ measurements made by using submersible[5-7] and remote[8] instruments are therefore preferable. Thanks to its express nature, the method of remote sounding is promising. It possibilities are, however, limited by a spatial resolution that is inadequate for performing a number of tasks and by the small (tens of meters) depth of sounding, not to mention the fact that the equipment is expensive and complicated. The sounding depth and spatial resolution are increased by using submersible fluorimetric equipment.

The present work formulates the main principles of designing and constructing submersible fluorimetric instruments, presents formulas for calculating the threshold sensitivity of the submersible fluorimetric instruments given a specified measurement error, and presents a number of original results obtained by using the fluorimeters and spectrofluorimeters we created.

The distinction of submersible fluorimetric instruments is that they measure the intensities and spectra of luminescence with natural ultraweak concentrations of phytoplankton chlorophyll and dissolved organic substances, a limited electric power requirement, and the presence of a background of solar radiation and exciting radiation that is scattered by sea water. Their measurement error should not exceed single-digit percentage points.

The main principles of designing and constructing submersible fluorimetric instruments are rather general[9-11] and are determined by the purpose and operating conditions of submersible fluorimetric instruments. The standard submersible fluorimetric instrument consists of submersible and on-board units that are functionally connected by a conventional cable rope, although it is possible to use a submersible unit in a stand-alone mode. It is advisable to create the submersible unit in the form of functional modules: excitation, recording, hydrostatic pressure measurement, etc. Pulse xenon lamps (SSh-20, ISSh-5, etc.) are preferable as an excitation source. To achieve a high precision, the optical train of the submersible fluorimetric instruments should have two channels—working and reference channels. The use of a pulse source maintains its advantages when a strobed recording system is used. Operation of the on-board unit on line with a computer is desirable for information processing and storage.

In view of the fact that the main source of error in measuring weak light signals is the Schottky noise of the signal or light background,[8] it is possible to establish an analytical link between the energy, optical, and geometric parameters of submersible fluorimetric instruments, the concentration and cross section of the luminescence of the substance under investigation, and the error in measuring the intensity or spectrum of its luminescence under conditions of the absence (1) or presence (2) of a solar radiation background[11]:

$$n \simeq \frac{4\pi hcFL^2}{\alpha\eta\lambda KE\sigma lA\varepsilon^2}, \qquad (1)$$

$$n \simeq \left(\frac{Fhc\Omega\tau S\Delta\lambda}{\alpha\eta\lambda A}\right)^{1/2} \frac{4\pi L^2}{K\sigma lE\varepsilon}, \qquad (2)$$

where E is the energy of the light pulse at the outlet of the excitation channel, n is the number of molecules per unit of volume, σ is the luminescence cross section of one molecule, O is the angular aperture of the recording channel, l is the length of that portion of the beam of exciting radiation that is captured by this aperture, L is the distance from the excitation beam to the inlet opening of the channel recording the area A, K(λ, Δλ) is the percentage of luminescence energy falling in the spectral recording range from λ to $\lambda + \Delta\lambda$; α is the transmission coefficient of the recording channel, ε is the noise-to-signal ratio at the outlet from the multiplier phototube, F is the parameter of the multiplier phototube from 1 to 2.5 for a large-gain multiplier phototube, η is the quantum efficiency of the multiplier phototube's photocathode; hc/λ is the energy of the recorded photon, τ is the detection time, and S is the spectral brightness of the light background.

Formula (1) makes it possible to estimate the minimum concentration of substance at which the luminescence intensity (for a fluorimeter) or spectrum (for a spectrofluorimeter) may be measured with a relative error of ε. Thus in the case of the luminescence of phytoplankton chlorophyll and a value of ε equal to 5 percent, the minimum concentrations equal 10^{-12} and 10^{-10} g/cm^3, respectively, for an implementable fluorimeter and spectrofluorimeter. Estimates based on formula (2) show that a light-protected dish should be provided in order to guarantee a high measurement precision in the daytime at a depth to several tens of meters (phytoplankton chlorophyll) and hundreds of meters (dissolved organic substances).

Analytical dependencies that are analogous to formulas (1) and (2) are used to estimate the parameters of the excitation channel light filter needed to exclude any effect on the signal by the background exciting radiation scattered by the sea water and to estimate the measurement error caused by the spatial instability of the exciting radiation.[11] Calculations confirm the suitability of submersible fluorimetric instruments for express high-current in situ measurement of the luminescence intensities and spectra of sea water.

The BF-1 submersible fluorimeter was our first instrument on which the aforementioned basic principles for designing submersible fluorimetric instruments were worked out and tested. The BF-1 is intended for in situ measurement of the luminescence intensity of phytoplankton chlorophyll or dissolved organic substances with a submersion depth to 200 m. The optical portion of the instrument is designed and constructed on the basis of the circuit of a single-beam photometer. The BF-2 submersible fluorimeter,[12] which is intended for in situ measurement of the spatiotemporal changes in luminescence intensity of phytoplankton chlorophyll or dissolved organic substances and the temperature and hydrostatic pressure of sea water to depths of 500 m, was created with an allowance for the experience accumulated in operating the BF-1. The instrument's optical train includes a reference channel that made it possible to reduce the error of measuring the luminescence intensity from one flash by up to 4 percent. Switching of the light filters to measure the luminescence intensity of phytoplankton chlorophyll or dissolved organic substances is accomplished without depressurization of the instrument. The resultant information is processed and stored by a computer that operates on line with the instrument.

The SFP submersible spectrofluorimeter,[11] which is the first instrument to investigate the luminescence spectra of sea water in situ to be described in the literature, was created to test the fundamental possibility of in situ recording of the luminescence spectra of phytoplankton and dissolved organic substances. The SFP has a spectral recording range of 400 to 800 nm. An MDR-4 monochromator has been used in the recording channel. The instrument has a submersion depth of up to 50 m. The SFK spectrofluorimetric system was developed with an allowance for the experience gathered in operating the SFP, and its manufacture is currently being perfected.

Metrologic support of the equipment has an important place in analyzing and interpreting the results obtained. The following method has been developed for the recording channel. The sensitivity threshold and linearity range are determined under laboratory conditions by using a set of solutions with specified concentrations of extracted chlorophyll a in ethanol. Long-term stability under field conditions is monitored by using a ruby monocrystal that is used as a highly stable luminescent etalon. Attenuation of the crystal's luminescence intensity to an acceptable level is accomplished by a set of standard neutral light filters. The scattering coefficient of the medium at which the scattered exciting radiation begins to affect the measurement results is determined under laboratory conditions by using a water and milk mixture. The turbidity of the mixture is increased until the appearance of a signal from the scattered exciting radiation, after which the scattering index of the mixture is determined.[10]

The instruments created by the authors were used to conduct numerous research projects in different water bodies throughout the world ocean. During measurements on the Black and Caspian seas, the BF-1 fluorimeter detected a small-scale dependence of the luminescence intensity of phytoplankton chlorophyll on depth (fine structure). The size of the layers amounts to 20-40 cm, and their amplitude varies in relation to the average value of the luminescence intensity from 10 to 30 percent.[13] Further research showed that the magnitude of the amplitude of the layers depends on the concentration of phytoplankton. In little-productive regions the amplitude is less than 10 percent, i.e., the fine structure is weakly expressed. Measurements made by a BF-2 fluorimeter on the 49th voyage of the M. Lomonosov scientific research vessel made it possible to calculate the spectral density of the vertical inhomogeneities of the luminescence intensity of the phytoplankton chlorophyll.[14] Standard estimates of the spectral density of the vertical inhomogeneities S(k) are shown in Figure 1.

As is evident from Figure 1 the results of individual soundings have distinctive features on the spectral curve in the range from 0.5 to 1 m^{-1}. To refine the type of spectral density of the vertical inhomogeneities, an averaged estimate of the normalized spectral density was calculated on the basis of the results of several soundings. The shape of this curve, which is plotted in a binary logarithmic scale, in the region $k < 0.5$ m^{-1} is close to the

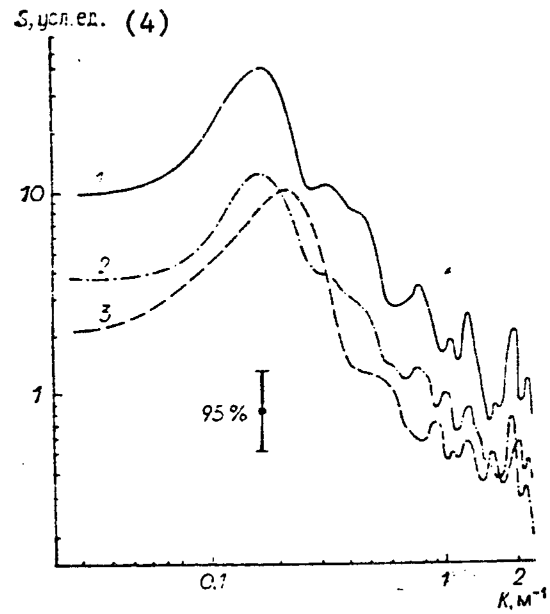

Figure 1. Estimate of the Spectral Densities of the Vertical Inhomogeneities of the Luminescence Intensity of Phytoplankton Chlorophyll

Key: (1) col., 5665; depth, 40-100 m; (2) col., 5665; depth, 0-200 m; (3) col., 5474; depth, 0-200 m. (4) arbitrary units

straight line $k^{-5/3}$, i.e., it is similar to the spectrum of passive hydrophysical fields such as, for example, temperature. This is explained by the fact that, for the given range of wave numbers, the characteristic turbulence dissipation time is much less than the phytoplankton's breeding time. Therefore, the formation mechanism of the spatial inhomogeneities for the phytoplankton chlorophyll are the same as for passive fields.

It should be noted that the measurements were made in little-productive regions of the Atlantic Ocean. In highly productive regions, formation of thin layers of phytoplankton chlorophyll is possible as a result of multiplication of the phytoplankton. Similar situations are presented elsewhere[15] and have been observed by the authors in the vicinity of intensive coloration of algae during the Black Sea stage of the 34th voyage of the Akademik Vernadskiy scientific research vessel.[12]

The SPF spectrofluorimeter was used to investigate the fluorescence spectra of phytoplankton chlorophyll in situ in the Caspean and Black seas (1986) and on the 49th voyage of the M. Lomonosov scientific research vessel (in the Alboran Sea and Portuguese polygon). The spectra recorded[11,16] have a form that is typical for the fluorescence spectra of chlorophyll a under natural conditions; however, the half-height of the spectrum ($\Delta\lambda_{0.5}$) and position of the spectrum's maximum (λ_{max}) changed as a function of the measurement region. Comparison of the resultant data and the physical characteristics of sea water

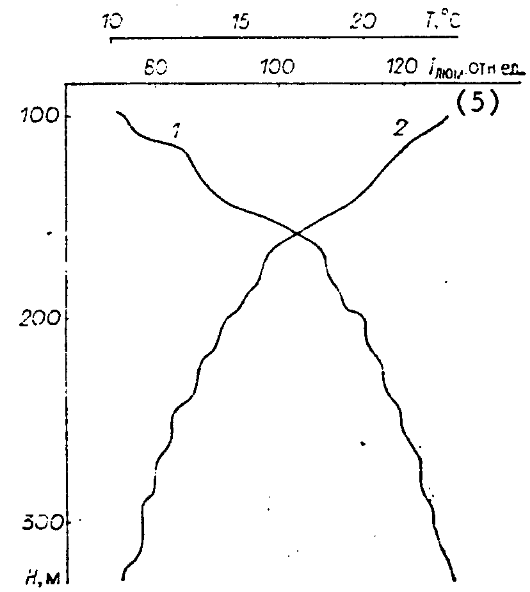

Figure 2. Vertical Distribution of the Luminescence Intensity of Dissolved Organic Substances (1) and Temperature

Key: 5. relative units

showed their close connection with salinity (S). The analysis results are presented in Table 1. It is evident from Table 1 that reducing salinity from 38 percent to 12 percent virtually doubles the fluorescence spectrum and causes a 10-nm shift in the spectrum's maximum to the long-wave region. It does not appear possible to draw an unequivocal conclusion regarding the causes for the dependence detected owing to a lack of data, specifically, regarding the species makeup of the phytoplankton in the measurement regions. It can only be noted that the specifics of the spectral forms of chlorophyll a in its native state determine pigment-pigment interaction,[17] the interaction of pigments with the proteins of the photosynthesis membranes,[18] and the coordination state of the chlorophyll's central magnesium atom.[19] All of the factors enumerated depend on both the species makeup of the phytoplankton and (to a large degree) on the external conditions of their habitation. A conclusion regarding what it is that is decisive in determining one spectral form of chlorophyll a or another can only be made on the basis of spectral luminescence research on monocultures of phytoplankton algae as a function of water makeup.

Table 1.

Region of measurements	Alboran Sea		Portuguese Polygon	Black Sea	Caspean Sea
λ_{max}, nm	678	679	680	683	688
$\Delta\lambda_{0.5}$, nm	16	20	22	26	31
S, % in thousands	38.06	36.45	35.68	17.97	approx or equal to 12

Research on the vertical profiles of the luminescence intensity of dissolved organic substances during the 49th voyage of the scientific research vessel M. Lomonosov revealed a staggered vertical distribution of the luminescence intensity of dissolved organic substances in a large portion of the stations in the Amazon polygon, where staggered temperature profiles were recorded. The vertical profiles of the luminescence intensity of dissolved organic substances and temperature for one of the polygon's stations are presented in Figure 2. The explicit correlation between the steps on the profiles of the luminescence intensity of the dissolved organic substances and temperature confirm the close connection of these hydrophysical fields. In fact, it has been noted in the literature[4] that the mean coefficient of the linear correlation of the luminescence intensity of dissolved organic substances and temperature equals -0.95; however, the mechanism of so strong a connection has not yet been explained. We are hypothesizing that this mechanism consists of the dependence of the viscosity of sea water η on the temperature T. There have been attempts to explain the profiles of the luminescence intensity of dissolved organic substances on the basis of Kalle's [transliteration] hypothesis regarding the formation of dissolved organic substances from dead phytoplankton, with the submersion rate of the dead phytoplankton being considered constant.[4]This is untrue since the submersion rate depends on the viscosity of the sea water, which in turn is strongly dependent upon temperature. Our calculations show that considering the dependence $\eta(t)$ explains the existing dependence $I = I_0(1 + \alpha T)$ of the luminescence intensity of dissolved organic substances on temperature with a negative coefficient α and predicts a value for the coefficient of α that either equals or approximates $-0.03\ K^{-1}$. Processing the data from our measurements showed that the average observed values of α coincide with the theoretical values. The strong (two- to threefold) deviations of the observed values of α from the theoretical values for certain intervals are probably connected with horizontal displacements of sea water from neighboring regions with more or less bioproductivity.

After considering the hypothesis regarding the formation of luminescing fractions of dissolved organic substances as a result of the decomposition of particles of biological origin, it is possible to hypothesize that a change in luminescence characteristics is possible during the process of the qualitative transformation of these particles. Measurements of the luminescence spectra of dissolved organic substances that were made in different water bodies and at different depths did not reveal any differences between them.[4] It is possible to hypothesize a difference in the excitation spectra of the luminescence; however, the number of such measurements is still insignificant. To test our hypothesis we measured the vertical profiles of the luminescence intensity of dissolved organic substances during excitation in different segments of the spectrum. The measurements were made on a BF-2 fluorimeter. Light filters with $\Delta\lambda_{0.1}$ = 340 to 390 nm and 410 to 450 nm were used for the excitation, and filters with respective values of 480 to 520 nm and 540 to 580 nm were used for the recording. The vertical distribution of the luminescence intensity in the range from 540 to 580 nm was also measured during excitation in a band from 340 to 390 nm. The measurement results for one of the stations in the Atlantic Ocean are presented in Figure 3. As is evident from Figure 3, there is a significant difference between curves 1 and 2. The course of curve 1 correlates with the beginning of the temperature jump, whereas that of curve 2 does not correlate. Similar results were obtained for other stations as well as during work in the Sea of Japan. The results obtained confirm the differences in the excitation spectra of the luminescence of dissolved organic substances close to and away from the layer of the jump. The similar shape of curves 1 and 3 qualitatively confirms the constancy of the luminescence spectrum of the dissolved organic substances. The difference between the shapes of curves 1 and 2 may be explained by the fact that a comparatively short-lived fraction of dissolved organic substances with a luminescence that is not effectively excited in the range from 410 to 450 nm is formed during the process of the decomposition of sea plankton. Remaining after the decay of this fraction are long-lived fractions that luninesce both in the range from 340 to 390 nm and in the range from 410 to 450 nm, which is confirmed by the similarity of curves 1 and 2 for depths greater than 200 m. The conclusions presented are in good agreement with the hypothesis regarding the conservative and nonconservative portions of the yellow substance.[10]

The results presented show the importance of using submersible fluorimetric instruments in oceanographic research. It seems virtually impossible to obtain these results by using other methods. A complete explanation of the results obtained requires further research

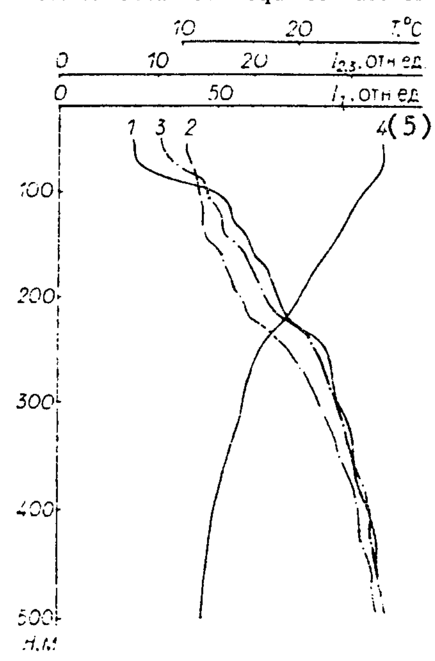

Figure 3. Vertical Distributions of Luminescence Intensity of Dissolved Organic Substances (1-3) and Temperature (4)

Key: 1. Excitation, 340-390 nm; recording, 480-520 nm; 2. Excitation, 410-450 nm; recording, 540-580 nm; 3. Excitation, 340-390 nm; recording, 540-580 nm; 5. Intensity measured in relative units involving more advanced equipment and methods, specifically a submersible spectrofluorimeter to record luminescence excitation spectra.

It may turn out to be extremely useful to use submersible fluorimetric instruments for studying internal water bodies, i.e., lakes and water reservoirs. Fluorimetric measurements of the phytoplankton concentrations and luminescing fractions of dissolved organic substances permit express determination of the level of waters' trophicity and judgment of the ecological condition of water bodies.

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Boiling Water Reactor—Optimum for AES

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[Article by G. N. Kruzhilin, corresponding member USSR Academy of Sciences, Ye. P. Ananyev, doctor of technical sciences, and I. S. Dubrovskiy, candidate of technical sciences, Power Engineering Institute imeni G. M. Krzhizhanovskiy]

[Text] The accidental failure of the boiling water graphite-moderated RBMK reactor at the Chernobyl AES with the burnthrough of its fuel elements elements (the fuel elements in the core) and the entrainment of a large amount of highly radioactive substances to populated territory with tragic consequences made the problem of AES safety much more urgent. The direct causes of this accident were organizational errors in managing the AES and a number of flagrant violations of operating rules by duty personnel that lead to the appearance of a positive "steam" reactivity coefficient when the reactor was at a low power level and, as a result, to an uncontrolled runaway of the prompt reactor. This reactivity effect in RBMK was known and considered admissible since it was completely suppressed by the reactor control and protection system and, furthermore, applied to a range of power levels that is far from the reactor's loads under operating conditions. After the accident at the Chernobyl AES the suppression of this unfavorable effect by the control and protection system in all operating RBMK reactors was intensified so as to completely prevent the possibility of an uncontrolled runaway of the reactor's power level. The enrichment of the fuel with uranium 235 was increased accordingly, because of which the fuel component of the costs of producing 1 kWh of electric power increased somewhat.

We will note that an analogous pressure tube boiling water power reactor with a heavy-water neutron moderator and a positive "steam" reactivity coefficient has been operating successfully in England since 1968.

Unlike an RBMK, the pressurized water-moderated, water-cooled reactor [VVER] does not have any power level zones with a similar unfavorable change in reactivity. In this reactor, on the other hand, in the event of an arbitrary increase in the power level over the specified level for some reason or other, the water temperature in the core increases. As a result, its density decreases, and the reactor's reactivity decreases accordingly. Thanks to this, the fluctuation in power level in the direction of an increase ceases. As is known, in this case, as the water density decreases, the process of the neutrons' moderation deteriorates,and the parasitic absorption of thermal neutrons in it is reduced, with the first process appearing more strongly than the second, thanks to which the core's reactivity decreases. The water-moderated, water-cooled reactor thus has internal nuclear safety.

Furthermore, the designs of modern AES with water-moderated, water-cooled reactors provide for the possibility of a graver accident in the reactor core's cooling system with a break in the main pipeline up to 500-600 mm in diameter in the loop circulating water through the reactor. In accordance with the established terminology, such an accident is termed a maximum design accident. In view of this, systems for emergency cooling of the core are being created at AES so as to prevent the burnthrough of the core under similar extremely grave accident conditions and to thereby prevent the fission products of uranium and plutonium nuclei with an enormous total radioactivity from leaving the core.

Considering the world experience with respect to the reliability of welded vessels under pressure, as far as inspection on the part of the boiler inspection is concerned, the probability of a break in the aforementioned pipelines is estimated as being between 10^4 and 10^5 reactor-years. This means that in 30 years of the operation (life) of 3,300 reactors only one accident of this type is likely. In addition, thanks to the aforementioned measures to cool the core in a similar accident situation, its burnthrough and, consequently, the escape of nuclear fuel fission fragments from it are even less probable. Measures are nevertheless being taken at AES to protect the public and surrounding locale. For this purpose, a spherical pressurized reinforced concrete cap (protective jacket or containment) is being erected over the reactor so that, in the event of an accident in which a large amount of radioactivity leaves the reactor's core, this reactivity will remain within the confines of the AES and not proceed into the environment. The containment is designed for a specific internal stream pressure that occurs owing to the partial evaporation of hot water when the circulation loop pipeline breaks. Also provided is intensive condensation of the steam formed inside the containment by spraying cold water through a special pipe system or special units with a large amount of ice pieces that are kept at a temperature of about -10°C thanks to continuous blowing with air.

Such a containment was erected over the first 60-MW water-moderated, water-cooled power reactor in the United States, which was designed by Westinghouse and Shippingport. Containments were also installed over each of the two existing steam generators. In this regard the reactor's chief designer Simpson wrote the following at the time[1]:

"It is obvious that protective jackets are expensive and will be eliminated in time. We consider it very unlikely that these devices will ever function. But to double the safety at the first commercial AES we considered it necessary to construct these expensive structures...."

It was precisely in the United States that practice proved that containment is in fact necessary at an AES. In 1979 an accident involving the burnthrough of the core unfortunately occurred at a 960-MW reactor at Three Mile Island, an AES with a water-moderated, water-cooled reactor. But thanks to the presence of protective containment there were no large emissions of radioactivity beyond the confines of the AES.

This grave accident in the United States, like the one at the Chernobyl AES, occurred because of the erroneous behavior of duty personnel. The human factor was thus manifested in a negative manner. Simpson's aforementioned prediction about the lack of a need for containment did not come to pass precisely because this factor was not taken into account. The equipment and designs of the AES overall were always implemented with a guarantee of the elimination of similar accidents. The required understanding of this problem on the part of physicists and designers was of course there. Now, after the aforementioned accidents, it is clear that containments over reactors are above all needed because of possible erroneous actions on the part of the operators working at reactors.

In addition, the events at the AES in the United States showed that a cap over the reactor, i.e., a containment, fully protects the public and territory adjacent to the AES from damage by radioactivity in the event of a burnthrough of the reactor, i.e., in the event of the most catastrophic accident at an AES. In all likelihood, because of this, public opinion in the United States, as in other countries (as may be judged by the press), toward the accident at the Chernobyl AES, where pressurized boxes with equipment assemblies could only partially play the role of containment, was calmer than in our country.[2] Only in Sweden has the public expressed opinions regarding a failure at an AES. In other countries, nuclear power generation is developing normally with the construction of new AES as the demand for electric power increases. In France, for example, more than 70 percent of all electric power is produced at AES. Japan is especially noteworthy since its territory is distinguished by high seismic activity. To date, 33 high-power water-moderated, water-cooled reactor power and pressure tube boiling water reactors are operating in Japan for a total electrical capacity of about 30 million kW.

As is known, pressure tube boiling water water-moderated, water-cooled reactors, i.e., boiling water-type reactors, which were first created by the American firm General Electric, are widely used in foreign AES together with water-moderated, water-cooled reactors.[3] Table 1 presents the installed capacity and number of units and mean values of the capacity factors in 1986 at AES with boiling water-type [VK] and water-moderated, water-cooled [VVER] reactors.

Table 1.

Country	Reactor Type	Total Electric Capacity, MW	No. Units	Capacity Factor, %
Sweden	VK	7,295	9	82.4
	VVER	2,160	3	—
Japan	VK	12,917	16	71.0
	VVER	11,438	15	82.3

Table 1. (Continued)

Country	Reactor Type	Total Electric Capacity, MW	No. Units	Capacity Factor, %
FRG	VK	7,219	7	80.4
	VVER	9,702	9	78.3
United States	VK	27,483	30	49.3
	VVER	55,511	60	63.2
France	VK	—	—	—
	VVER	43,700	43	—

Throughout the world AES have approximately half as many boiling water-type reactors as water-moderated, water-cooled reactors. this is mainly because at the very beginning of the development of nuclear power generation it was rightly assumed that it would be more difficult to prevent radioactivity from escaping through the ventilation pipe beyond the confines of the AES in a unit with a boiling water-type reactor as opposed to a water-moderated, water-cooled reactor. In fact, the core of a power reactor consists of about $40 \cdot 10^3$ fuel elements about 10 mm in diameter with a zirconium jacket less than 1 mm. The service life of the fuel elements in a reactor is at least 3 years. It is therefore natural to expect that during this time span several fuel elements will become faulty. As a result, fission fragments will end up in the steam and, after the turbine condenser, they will exist from the loop through the extracting ejector. Depending on the engineering decisions that have been made they will then proceed together with the extracted air to special gas activity reduction system devices, i.e., activity suppression units for processing and holdup, after which they are extracted together with the ventilation air flows into the ventilation pipe and dumped outside.

Meanwhile, in a water-moderated, water-cooled reactor with steam generators the radioactivity from faulty fuel elements will not enter the steam going to the turbine at all. Thanks to this the aforementioned problem does not exist at all. Although difficulties due to fission fragments from faulty fuel elements do nevertheless appear in water-moderated, water-cooled reactors, they do so in much weaker form. They remain in the reactor's primary loop, where they are subjected to "holdup," i.e., self-decay, and exit this loop only in a relatively small quantity together with small water leaks and during repairs.

It then became clear that in reality the conditions with respect to the aforementioned exit of radioactive gases during the operation of boiling water-type reactors are significantly better than was expected. Specifically, one Japanese publication communicates that in their pressure tube boiling water reactors $500 \cdot 10^3$ fuel elements lived out their full service life without a single case of failure of their zirconium jackets.[4] Specifically, this extremely important fact is connected with the use of a neutral oxygen water-chemical regime, during which the fuel elements' surface is not covered with corrosion products at all, thanks to which it is subject neither to superheating nor corrosion under sediment. This important result, which attests to the reliability of the fuel elements' leaktightness, is also confirmed by the multiyear experience of the operation of a single (prototype) domestic VK-50 pressure tube boiling water reactor at the AES in Dimitrovgrad. Use of a neutral-oxygen water-chemical regime at the AES began in 1978. As a result, the fuel element jackets became clean, i.e., without deposits of corrosion products on them, and cases of their losing their leaktightness ceased. Thanks to this the radioactivity of the gases released to the ventilation pipe of the AES amount to about 4 Ci/day, whereas they were much higher before.

Initially there was one very fundamental outcry against VK reactors in regard to the obvious instability of the water boiling process owing to the formation and growth of steam bubbles and their movement. The result was the danger of an uncontrolled runaway of the power level of this type of reactor owing to a fluctuation in the density of the steam and water mixture since in this type of reactor water is the sole neutron moderator (whereas in an RBMK graphite-moderated boiling water reactor graphite is the main neutron moderator). An active proponent of this viewpoint at the Institute of Atomic Energy was the great authority Professor S. M. Feynberg, who was a close associate of I. V. Kurchatov, the greatest specialist in the field of reactor physics. The successful operation of this type of reactor in a number of foreign countries and the many years of operation of the VK-50 pressure tube boiling water reactor in our country are convincing confirmation that no such danger exists in reality.

Considering what has been said, it seems advisable to raise the question of the need to use VK pressure tube boiling water reactors together with water-moderated, water-cooled reactors at such AES. They would replace the RBMK reactors taken out of production after the Chernobyl accident. this would ensure the competitive progressive development of the designs of these two types of reactors and would, when necessary, permit a quicker pace of constructing new AES.

The VK reactor operates at a pressure of 70 kgf/cm^2, whereas water-moderated, water-cooled reactors operate at a pressure in the primary loop of 15—160 kgf/cm^2. Steam generation in a pressure tube boiling water reactor occurs directly in its vessel, because of which it does not have any steam generators. Thanks to this it is more reliable to operate than, for example, the VVER-1000 water-moderated, water-cooled reactor, which has four steam generators with heating surfaces made of stainless steel tubes 12/1.2 mm in diameter, the total number of pieces amounting to 62,592. The latter are subject to corrosion-erosion damage requiring the reactor to be shut down.

When a unit with a pressure tube boiling water reactor is created, the costs of the equipment as well as the erection and subsequent repair operations are reduced accordingly. It is also important that the location of equipment in this version be much more compact, because of which erecting a reliable containment, i.e., protective reinforced concrete cap over the reactor, is accordingly simpler than in the case of a water-moderated, water-cooled reactor. And this fact is significant since the containment performs the critical task of preventing the emission of radioactivity beyond the confines of the AES in the case of the type of grave accident mentioned above. Considering this, work should be undertaken to perfect the reactor. In view of this we consider it advisable that the space of the containment be filled with inert gas—nitrogen or carbon dioxide—in order to prevent the possibility of an explosion due to the presence of hydrogen, which may form under accident conditions when the core burns through in both water-moderated, water-cooled and pressure tube boiling water reactors.

In addition, a pressure tube boiling water reactor has a strongly negative "steam" reactivity coefficient, which gives it a high degree of nuclear safety that is even somewhat higher than that of water-moderated, water-cooled reactors since, in the event of an upward jump in the power level due to steam formation, the density of the moderator and, accordingly, that of the neutron moderator will drop more strongly than in a water-moderated, water-cooled reactor.

Finally, it is essential to note the possibility of creating a pressure tube boiling water reactor with natural water circulation and a unit electrical capacity of about 500-600 MW.[5] Such a reactor would be distinguished by a high degree of operating reliability and complete safety with respect to the maximum design accident in the event of a water leak owing to a break in the circulation loop pipeline since the design version under examination does not have any such pipeline.

Thanks to the positive features enumerated above it is entirely possible that the boiling water-type reactor will in the future displace the more complicated and expensive water-moderated, water-cooled reactors.

Our country has both the scientific-technical and manufacturing capabilities to create pressure tube boiling water reactors. One should above all recall the enormous experience that has been accumulated with regard to operating the VK-50 reactor, including with respect to the reactor's physics and the specific conditions of controlling it. There is a rather large amount of knowledge regarding the hydrodynamics and thermophysics of its processes as well as knowledge about the rather difficult (in this case) problem of steam separation. Undoubtedly, the required design experience has also been accumulated during the creation of the VK-50 and during the development of the designs of vessels, pipelines, pumps, and other equipment for water-moderated, water-cooled reactors, which are also suitable for boiling water-type reactors.

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Some Problems in Generating Power of AES in 12th Five-Year-Plan

907F0120A Moscow ELEKTRICHESKIYE STANTSII in Russian No 11, Nov 89 pp 33-36

[Article by R. A. Dubrovskaya and D. L. Faybisovich, engineers, All-Union State Planning and Surveying and Scientific Research Institute of Power Generation Systems and Networks (Energosetproyekt), under "Nuclear Power Plants" rubric: "Some Problems in Generating Power of AES in 12th Five-Year-Plan"; final paragraph is a note from the editorial staff of ELEKTRICHESKIYE STANTSII]

[Text] The installed capacity of AES as of 1 January 1989 amounted to 34.5 GW, and in 1988 they produced 215.4 GWh of electric power. The fraction of AES in the total production of electric power in our country and, above all, in its European section is increasing steadily, as is seen by the following data (as percentages of the total production of electric power throughout the country):

Scale of Production of Electric Power by AES	1975	1980	1985	1988
Throughout country	2.0	6.0	10.9	12.7
In European part (without the Urals)	3.1	10.0	18.5	22.0

A great deal of importance is being given to further development of nuclear power generation as one of the main directions in improving the country's fuel-and-power balance. Most of the increase in the production of electric power in the territory of the European section of the country should be accomplished during the years of the 12th Five-Year-Plan. It is planned that by 1990 the relative share of the electric power produced by AES will increase to 14 percent of the total throughout the country. This is also characteristic for a number of other countries. Materials of the International Atomic Energy Agency [IAEA] thus communicate that in 1986 the electric power produced by AES amounted to 15.6 percent of the total world production. In a number of countries (France, Belgium, Switzerland), AES produce 40 to 60 percent of all the electric power produced.

During the previous period, the development of nuclear power occurred both by increasing the capacity of power station units and increasing the installed capacity of electric power plants under construction. In the domestic practice 440-MW units replaced the first 210- and 365-MW units, and since 1980 the unit power of units introduced increased to 1 million kW. In 1983 an RBMK-1500 reactor with an electrical output of 1.5 million kW was put into operation at the Ignalina AES. This unit included two turbine sets with a capacity of 750 MW each. The unit power for an AES reactor that has been achieved in our country corresponds to the level of those at the largest foreign AES.

The largest turbogenerator set installed at an AES in our country has a capacity of 1,000 MW, whereas the largest one abroad has a capacity of 1,330 MW (the AES at Brokdorf in the FRG).

The installed capacities of individual AES have increased significantly in recent years. The capacity of the largest AES in the country (Leningrad, Kursk) reached 4 GW. In 1990 the Zaporozhye AES will reach an installed capacity of 6 GW. If, at the end of the 11th Five-Year-Plan, AES with an installed capacity of 3 million kW or more accounted for 42.3 percent of the total capacity of AES, then in view of the AES now being planned or constructed, this figure will increase.

The largest AES abroad are currently Fukushima (Japan) with 7.7 GW, Bruce (Canada) with 5.5 GW, Gravelines (France) with 5.4 GW, etc.

The high unit power of power station units and power plants and the requirement that actions on the operation of a nuclear power plant's reactors during deviations in the power system's mode from the normal (including in emergency situations) be kept to a minimum dictate the need to carefully work out the problems of generating the power of AES.

The "Normy tekhnoogicheskogo proyektirovaniya AES" [Norms for Technological Design of AES] and "Rukovodyashchiye ukazaniya po proyektirovaniyu energosistem" [Directives Regarding Designing Power Generation Systems] impose stricter requirements on schemes for generating the power of an AES when compared with those for other types of electric power plants. In accordance with these requirements, generation of full power should be ensured in all stages of erection of an AES (the unit, stage) during the power generation system's normal operating modes and during the deviation of any outgoing electrical power line or busbar transformer without action by the emergency automation equipment system to off-load the nuclear power plant's units.

In repair modes related to the disconnection of an individual open-wire pole line and in emergency modes during failures of switches in the outdoor switch gear of the AES or in its relay protection devices, the stability of the AES should be guaranteed by the actions of the emergency automation equipment system.

Satisfying the specified fundamental policies regarding the operation of AES in the power generation system requires the following:

selecting the main circuits of the electrical connections;

—erecting electrical power lines in sufficient numbers and with significant carrying capacities;

—developing intersystem connections for the USSR Unified Power Generation System;

—ensuring the controllability of AES during emergency modes in the power generation;

Generalizing the experience in developing schemes for generating the power of an AES that was accrued at the All-Union State Planning and Surveying and Scientific Research Institute of Power Generation Systems and Networks makes it possible to draw several conclusions.

The main circuit of electrical connections must satisfy the following principal requirements:

—damage to or failure of any of the switches in the RU [not further identified] should not result in the disconnection of more than one power station unit or more than that number of outgoing open-wire pole lines and busbar autotransformers that is permissible in accordance with the operating stability conditions set for the AES and power generation system;

—it should be possible to repair any switch without disconnecting a connection (power station unit, outgoing open-wire pole line, busbar autotransformer).

It is preferable that two voltages be used to generate the power of an AES. This permits reliable and economical coverage of the load of the adjacent region at a voltage of 220 or 330 kW, reduction of the overflow of power and electric power along the networks of these two voltages, and a significant reduction in the amount of networks that must be constructed in order to start up the first unit. Another advantage of connecting a portion of the units to 220- and 330-kW networks is that it increases the stability of the generators of the AES in the event of a short circuit in the peripheral network. This is due to the fact that when a short circuit is separated, a slowing action on the load directly connected to the buses of the AES is more effective than is connecting it after a high reactive resistance to a higher-voltage network. In addition, using two higher voltages to generate the power generally causes a reaction on the part of the institute that designs AES generators, i.e., the All-Union State Institute for the Design and Planning of Nuclear Power [Atomenergoproyekt], since it increases the capital investments required to construct an AES. In general, however, from the standpoint of the power generation system overall, the capital investments in the AES system, i.e., the electrical network, generally turn out to be the smallest when two voltages are used in an electric power station. If the reduction of losses of electric power in the network are added on, this decision will undoubtedly be both technically and economically well founded. This is especially important when power generation systems are operating under conditions of full cost accounting and self-financing.

The analysis of the main circuits of the electrical connections of AES and the conditions of their operation in the power generation system that was conducted showed that using (in both existing AES and AES in the design stage) circuits with two systems of emergency generator buses with three switches to two circuits (a 3/2 scheme) and four switches to three circuits (a 4/3 scheme) meets the stipulated requirements. In the case where there is a voltage of 220 kV and where one AES unit is connected to these buses, using a binary system of buses with a bypass bus should be considered completely acceptable.

A significant amount of power grid construction is necessary to generate the capacity of AES. The high unit power of power station units and power stations has determined the use of very high voltage electrical networks for the specified purpose. The dynamics of the change in tying the capacity of AES into electrical power networks with separate nominal voltages is presented in the following table.

Electrical Network With Voltage, kV	Installed Capacity of AES, %		
	On 1 Jan 1986	During Course of 12th Five-Year-Plan	On 1 Jan 1991 (acc. to plan)
750	28.5	55.0	39.5
500	10.5	21.0	13.0
330	46.5	24.0	40.5
220	14.5	—	7.0

It may be noted that the trend toward an increase in using 500- and 750-kW voltage networks to generate the capacity of AES will intensify. For a number of AES that are currently being designed, it is proposed that their power be generated by using a voltage of 1,150 kV.

During the years of the 12th Five-Year-Plan 76 percent of the unit capacity introduced at AES will produce power into the network at voltages of 500 and 750 kV. Generating the capacity of a unit over the course of 1 year will require that one or two long high-power open-wire pole lines from the AEs be introduced and that step-down substations with lines running from them also be constructed. The total scales of the required electric power network construction to produce this power are very large. The total length of the open-wire pole lines with these voltages directly leaving electric power station buses amounts to about 5,500 km, including about 3,200 km with a voltage of 750 kV. If the need to construct 3,200 km of 330-kV open-wire pole lines and the corresponding number of 330-, 500-, and 750-kW substations is added to this figure, the problems related to overcoming the aforementioned concentration of electric power network construction become comprehensible.

The amounts of construction of ultra-high-voltage construction presented do not include the need for the respective development of intersystem links to the USSR Unified Power System that is caused by the operation of nuclear power plants. As is known, the large numbers of AES being introduced and the basic operating mode of AES have resulted in the appearance of significant modal power capacity overflows in the networks of the USSR Unified Power System, above all, in the west-east direction. Providing this type of mode requires intensifying the intersystem links of the USSR Unified Power System. For the specified purposes, no fewer than 1,000 km of 500- to 750-kW open-wire pole lines (Lipetsk-Tambov, Tanbov-Penza, Smolensk AES-Belorussian AES) must be added to the amount of electrical power network construction presented in the 12th Five-Year-Plan. It may be noted that one of the channels along which modal capacity overflows will be realized in the USSR Unified Power System given the slated AES construction program will be the 1,500-kV Ekibastuz-Tambov PPT [not further identified], which is currently under construction.

One measure to reduce intersystem capacity overflows and, consequently, reduce the requirements regarding the carrying capacity of intersystem links would be the operation of AES units in a demand-adaptable mode. The world practice in designing and operating AES permits the operation of power reactors in the variable portion of a load graph, i.e., a load-following mode. Besides in France, operation of AES in a load-following mode is being introduced at AES in Sweden and South Korea.

The previously specified program for the construction of electrical networks with a voltage of 750 kV in the 12th Five-Year-Plan surpasses the amount of open-wire pole lines and carrying capacity with this voltage that were introduced during the two previous five-year-plans. This has led to problems in the respective provision of shipments of primary electrical engineering equipment. Thus, in view of the need for this equipment at electric power plants as well, the demand of electrical networks for transformers, shunt reactors, and 750-kV switches will increase 1.5-fold when compared with the respective shipments during the years of the 11th Five-Year-Plan. The required resources of materials to construct the open-wire pole lines and carrying capacity to generate the capacity of AES in the 12th Five-Year-Plan is estimated at 200,000 tons of aluminum cable steel reinforced (based on the weight of copper) and 230,000 tons for the metal structures of supports.

Implementation of the program for electrical power network construction to generate the capacity of AES in the 12th Five-Year-Plan is connected with assimilating capital investments in the amount of 0.9 billion rubles, including for construction and erection operations in the amount of 0.6 billion rubles.

Ensuring the controllability of AES under normal modes and under emergency conditions of the power system's operation is very important both for ensuring the stability and reliability of the electric power plants themselves and that of the USSR Unified Power System.

Erecting a sufficient number of open-wire pole lines to generate the capacity of AES and strengthen intersystem lines does not exclude the likelihood of a short-term reduction in voltage in the event of a short circuit close to the buses of electric power stations, deep synchronous pivots, and deviations of the frequency in a power generation association that are caused by emergency power shortages. This problem is especially acute in regard to AES connected to links between individual power generation enterprises. This applies particularly to such electric power stations as the Kalinin, Balakovo, and Rostov power stations and a number of others.

An AES should permit the following to ensure the stable operation of nuclear power plants and the power generation system as a whole:

—stable auxiliary operation and process protections under conditions of the occurrence of short circuits, synchronous pivots, etc., in the power system;

—preservation of auxiliary operation in the event of emergency reductions in voltage and frequency;

—emergency off-loading upon the action of the emergency automation equipment system in the event of a disruption of the circuit of electrical connections with the power generation system in repair and emergency modes. This type of emergency load is above all necessary to ensure the reliability of the power generation system, including the reliable operation of the AES included in the power generation system.

Conclusions

1. The fraction of the capacity of AES connected to the highest voltages of the electrical network (500 to 750 kW) is increasing and will amount to about 80 percent by 1990.

2. Using two nominal voltages to generate the power of AES is the most economical decision, and it also increases the operating stability of AES.

3. Guaranteeing the reliable and stable generation of the power of an AES requires a significant amount of construction of 500- to 750-kV networks. During the years of the 12th Five-Year-Plan the extent of the 750-kW network should increase 1.6-fold.

4. The base operating mode of an AES determines the appearance of significant mode capacity overflows, which requires respective intensification of intersystem connections.

5. Erecting enough open-wire pole lines to generate the power of AES does not eliminate any requirements regarding guaranteeing the controllability of AES in the event of accidental drops in frequency or voltage or in the event of action of the emergency automation equipment system.

From the editors

In this article R. A. Dubinskaya and D. L. Faybisovich have examined the problems of generating the power of AES under the conditions of their planned development during the 12th Five-Year-Plan. The article is formulative in nature. In the opinion of the editorial staff, some of its positions are indisputable. In view of the importance and timeliness of the problem of developing and locating AES, their functional reliability, generation of their power, the circuits of their primary connections, the unit power of units, and the controllability of power generation systems during normal and emergency modes, the editorial staff is, by publishing this article, inviting representatives from the power generation community and the leading operation and planning organizations (the Central Dispatcher Administration of the USSR Unified Power System, All-Union State Institute for the Design and Planning of Nuclear Power, etc.) to take part in a discussion of these problems on the pages of our journal.

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Development of Regulations for Maintenance and Repair of Primary Equipment of AES

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[Article by A. I. Kolesnik, engineer, All-Union Scientific Research Institute of AES]

[Text] This article examines several aspects of the development of a maintenance and repair regulation based on the equipment of an AES. The most characteristic features of the implementation of these repair operations are as follows:

—repair operations can generally only be conducted upon the partial or complete shutdown of the unit. In a unit with a VVER-440 reactor, for example, repair of the reactor is conduced only upon a complete shutdown whereas repair of the turbine is possible provided the power level is no more than 50 percent of the rated level;

—related (preparatory) operations entailing large inputs of labor, resources, and time are conducted. For the K-220-44 turbine, for example, the total duration of work to center the rotor and bolt together the coupling halves and the bearings takes more than 2 days.

The task of developing regulations for maintenance and repair operations for the specified type of equipment therefore entails not only determining the individual time frames for the repair and for operations on the subassemblies and equipment but also their combination.

It is proposed that this task be accomplished by selecting the most adequate mathematical model for each subassembly. Next, functional and layout block diagrams are used as the basis for investigating the dependence of losses owing to the underproduction of electric power and losses connected with labor and resource expenditures on the makeup of the repair operations. After this, the maintenance and repair regulations are constructed by using alternative calculations.

In view of the fact that the demand for electric power is highest in the autumn-winter period, the maximum (from a duration standpoint) scheduled repairs (including overhaul and medium repair of individual units) are conducted once a year in the spring or summer and last from 30 to 70 days. In addition, it is proposed that routine repair lasting a total of 6 to 10 days be conducted for equipment nodes that wear out quickly. These time frame may vary in each specific case depending on the condition of the equipment and a number of other factors.

It is entirely understandable that within these time frames personnel can successfully conduct repair operations and eliminate any failures that arise during the operating process. In a significant number of cases this can be done. During the occurrence of leaks in the piping system in the condenser, for example, the pressure (vacuum) changes. In the event of sizable damage, however, the parameter (in this case the pressure) does not reach its limit allowable value, and its rate of increase is not high. It is therefore advisable to eliminate such a failure during scheduled repairs. In the event of a large change in parameters, for example, in the case of a rupture of the turbine's pipeline, shutdown of the unit (in this case the turbine) and implementation of repair operations are characteristic.

If the equipment is new, the damaged section is generally restored (for example, an air hole in a pipeline is eliminated). If the equipment has been in operation for a long time, replacing it is frequently advisable (for example, a bearing that has already outlived its service life).

It is also understandable that in a number of cases it is advisable to conduct scheduled repairs without waiting for the appearance of signs of failure, i.e., to disassemble, examine, revise, and restore failed nodes.

With regard to the noted features of implementing maintenance and repair operations, the author of the present article proposes using a mathematical model with the following rules for conducting preventive and unscheduled repairs. (Here and henceforth this will refer to repair conducted after the failure of equipment.)

At the moment that a component begins to operate, the implementation of complete preventive repair given the operating time τ_1 is planned. If the equipment's operating time is less than τ_1 and a failure has occurred, then unscheduled repair begins at that moment. In addition, at the moment the equipment begins its operation the quantity τ_2 characterizing the rule for selecting the type of unscheduled repair (τ_2 being less than or equal to τ_1) is also planned. If a failure occurs during an operating life of of less than or equal to r_2, the minimum unscheduled repair is conducted. If the failure occurs during an operating time of $> \tau_2$, complete unscheduled repair is conducted. The moment complete restoration has been completed, the quantities τ_1 and τ_2 are replanned, and the processing of the functioning and servicing of the equipment is repeated. The proposed servicing scheme includes three particular cases, namely,

1. $\tau_2 = 0$: in the event of a failure full unscheduled repair is always conducted;
2. $\tau_2 = \tau_1$: in the event of a failure the minimum unscheduled repair is always conducted;
3. τ_1 = infinity: preventive repair is not conducted.

It is proposed that the specific losses per unit calendar time $c_s(\tau_1, \tau_2)$ be used as an optimization criterion.

Working jointly with V. V. Taratunin and A. G. Kamenskiy, the author analyzed the model. The main results are as follows:

1. The following optimization functional, which is solved by using numerical methods on a computer, has been derived:

$$c_y(\tau_1,\tau_2)=\frac{c_1\int_0^{\tau_2}\lambda(\tau)d\tau+c_2\frac{F(\tau_1)-F(\tau_2)}{\bar F(\tau_2)}+c_3\frac{\bar F(\tau_1)}{\bar F(\tau_2)}}{\tau_2+\frac{1}{\bar F+\frac{1}{\bar F(\tau_2)}}\int_{\tau_2}^{\tau_1}\bar F(x)dx+T_1\int_0^{\tau_2}\lambda(x)dx+T_2\frac{F(\tau_1)-F(\tau_2)}{\bar F(\tau_1)}+T_3\frac{\bar F(\tau_1)}{\bar F(\tau_2)}},$$

where F(t) is the distribution function of the failure-free operation time, $\bar F(t) = 1 - F(t)$ is the reliability function, $\lambda(t)$ is the failure intensity function, c_2 is the mathematical expectation of the cost of complete unscheduled repair, T_2 is the mathematical expectation of the duration of complete unscheduled repair, c_1 is the mathematical expectation of the cost of the minimum unscheduled repair, T_1 is the mathematical expectation of the duration of the minimum unscheduled repair, c_3 is the mathematical expectation of the cost of complete preventive repair, and T_3 is the mathematical expectation of the duration of complete preventive repair.

2. The proposed strategy is more optimum than is the case of servicing based on a variable operating life. Specifically, this means that it is advisable that the sequence of the implementation of scheduled repairs on AES units that are conducted in the spring-summer period be kept unchanged.

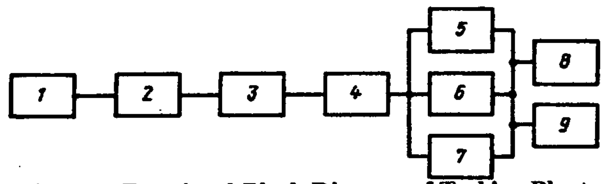

Figure 1. Functional Block Diagram of Turbine Plant

Key: 1. Turbogenerator set; 2. Moisture separator/reheater unit; 3. Deaerator; 4. No. 1 low-pressure heater; 5-7, Condensate pumps; 8 and 9, Circulating pumps

Structure of the losses resulting from underproduction of electric power. As an example we will examine the determination of the losses from the underproduction of electric power for a K-220-44 turbine plant. The maximum allowable relative power levels provided by the turbine equipment are presented in the following table.

Equipment	Power level, rel. units
Turbogenerator set	1
Moisture separator/reheater unit	1
Deaerator	1
No. 1 low-pressure heater	1
Condensate pump	0.75
Circulating pump	0.73

The performability of each unit of equipment ensures the performability of the turbine plant at the specified power level (for example, a condensate pump ensures operation of the turbine plant at a power that is 75 percent of the rated capacity). The turbine plant may be represented by using a parallel-series functional block diagram (Figure 1). In turn, the turbine plant is a component of the power station unit, which consists of (besides the turbine plant) a reactor unit and yet another turbine plant (Figure 2) [Figure 2 was omitted from the source text]. The underproduction of electric power may be determined as follows.

We will designate the condition of the j-th element (j = 1, 2, ..., 9) of the i-th turbine plant (i = 1, 2) at the point in time τ as $x_{ij}(\tau)$. We will assume that each element of the turbine plant may be in one of two conditions, fit for service or not. In the unfit-for-service condition, $x_{ij}(\tau) = 0$. In the fit-for-service condition, $x_{ij}(\tau)$ assumes a value in accordance with data presented previously (for example, for a circulating pump, $x_{ij}(\tau) = 0.73$). We will use $\varphi_i(\tau)$ to designate the structural function of the turbine plant, i.e., the maximum allowable power level. It is not difficult to understand that the structural function of the turbine plant will have the form

$\varphi_i(\tau)$ = min Unordered set: $x_{i1}(\tau)$, $x_{i2}(\tau)$, $x_{i3}(\tau)$, $x_{i4}(\tau)$, $x_{i5}(\tau) + x_{i6}(\tau) + x_{i7}(\tau) + x_{i8}(\tau) + x_{i9}(\tau)$.

If $\varphi_3(\tau)$ designates the structural function of the rector unit, the structural function of the power station unit may be represented as

$\varphi(\tau)$ = min Unordered set: $0.5\,[\varphi_1(\tau) + \varphi_2(\tau)]$, $\varphi_3(\tau)$.

The underproduction of electric power during the period in which the repair operations are conducted amounts to

$$Q = N_H \int_0^t [1 - \varphi(\tau)]\,d\tau,$$

where t is the duration of the repair operations, N_H is the rated electric power level, and $\varphi(\tau)$ is the value of the structural function at the point in time τ.

The losses arising from an underproduction of electric power amount to

W = QR,

where R is the specific cost of the electric power.

Determination of the underproduction of electric power during the implementation of combined operations is well illustrated by the following example.

We will assume that we must conduct a reactor repair lasting 10 days and a turbine repair lasting 20 days. This may be done after demanding that the underproduction that is the "joint fault" of both components be maximal (it corresponds to the area $A_1B_1C_1D_1$ in Figure 3a) or by not making this constraint (for example, in accordance with Figure 3b). For the rated power of a 440-MW unit it is not difficult to calculate that in the first case the underproduction of electric power will amount to 6,600 MWd, whereas in the second case it will amount to 7,700 MWd. This means that to estimate the extent of the underproduction of electric power it is necessary to first arrange the operations so that the underproduction is kept to a minimum.

Time, labor, and resource outlays. The procedure for determining the expenditures of time, labor, and resources may be reduced to the following sequence of actions:

—determining the set of preliminary and repair operations;

—estimating the characteristics of these operations, namely, the number of work stations, i.e., the maximum number of personnel that may be involved in the work, estimating the labor input, its cost, and the cost of resources;

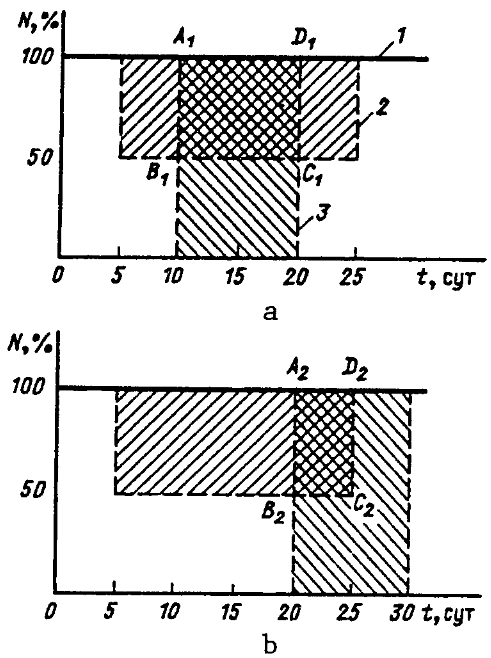

Figure 3. Example of Implementation of Combined Repair Operations on Reactor and Turbogenerator Set

Key: 1. Rated power level; 2. Reduction in power level to repair the turbine; and 3. Reduction in power level to repair the reactor (the y-axis represents the percentage of rated power; the x-axis represents time in days)

—determining all related preliminary operations for each repair operation;

—analyzing the possibility of combined implementation of repair and preliminary operations and determining the critical repair paths;

—estimating the total expenditures of time, labor, and resources.

In the planning of scheduled repairs, these problems are generally solved on the basis of existing standards and network graphs.[1] This same approach may be used when developing regulations for maintenance and repair operations. In this case, however, when the development of the maintenance and repair operations regulations entails the need to perform a large number of alternative calculations, plotting the network graphs may require great time expenditures.

It may turn out to be most effective to construct a layout block diagram, which the author has done for a turbogenerator set including a K-220-44 turbine and a TVV-220-2a turbogenerator (Figure 4).

For each type of operation specified on the diagram we will use the following designations: Q_i, the labor intensity of the i-th operation; n_i, the number of workstations for the i-th operation; and R_i, the resources expended for the i-th operation.

Table 1.

Repair or Preliminary Operation	Labor Intensity, man-hours	No. Workstations	Costs, rubles
Disassembly, repair, assembly of high-pressure casing	1,800	8	5,200
Disassembly, repair, assembly of low-pressure casing	1,300	8	3,700
Disassembly and assembly of No. 1, 2, 3, 4 bearings	15	3	40
Disassembly of coupling half, centering, etc.	1,800	18	1,800

We will now examine an example of using a layout block diagram. We will assume that we must repair a high-pressure casing and a No. 1 low-pressure casing [TsND-1]. On the basis of the diagram it is not difficult to determine that this requires performing operations 2, 4, 17, 18, 22, and 26. By using the characteristics of the reparability of the nodes that are presented in Table 1, it is easy to find the total characteristics, for example, the total labor intensity will amount to the following (no personnel are involved in the operations specified in item No. 26):

$Q_2 + Q_4 + 2Q_{17} + 2Q_{18} + Q_{22} = 4,760$ man-hours.

If it is assumed that the number of repair personnel is unlimited, the total duration of the scheduled repairs will amount to

$$\max\left[\left(\frac{Q_2}{n_2} + \frac{Q_{17}}{n_{17}}\right), \left(\frac{Q_4}{n_4} + \frac{Q_{18}}{n_{18}}\right)\right] + \frac{Q_{22}}{n_{22}} = 430 \text{ hours}$$

Constructing a maintenance and repair operations regulation. Earlier we used functional and layout diagrams to investigate the dependence of the losses resulting from an underproduction of electric power and the losses connected with expenditures of time and resources on the makeup of the repair operations.

For each node there are individual losses, i.e., inherent only to it (for example, for a high-pressure casing these are the losses connected with its disassembly, repair, and assembly), and combined losses (for example, the losses resulting from an underproduction of electric power in the event of combined repair of the high- and low-pressure casings). As far as the first group of losses is concerned, it is entirely natural to charge them to the respective node. As far as the combined losses are concerned, the following two boundary situations may be formulated.

The first of them is when the combined losses "are charged" to the other equipment nodes, and the second is when the node under examination is repaired individually and, naturally, all losses are charged to it.

It is understandable that the losses that are feasibly included in the cost of scheduled repairs of a node are no less than the respective individual combined losses required for maintenance and repair of this node.

We will now turn to a discussion of some practical results obtained by the All-Union Scientific Research Institute of AES when optimizing the maintenance and repair operation strategy for the turbogenerator sets at the Kola AES.

For each node of the turbogenerator set, they determined the frequencies of the scheduled repairs corresponding to both the boundary situations and the intermediate values of the costs of the scheduled repairs. The results of the calculations showed that the minimum cost of the scheduled repair corresponds to its minimum frequency and that the cost of the scheduled repair is at a maximum when it is conducted at the maximum frequency. Examples of the calculated frequencies for individual nodes of a turbogenerator set are presented in the following list.

Table 2.

Equipment	Order No. of Year in Cycle				
	0	1	2	3	4
Reactor	O+R	M+R	M+R	M+R	O+R
No. 1 turbogenerator set	O+R	R+R	M+R	R+R	O+R
No. 2 turbogenerator set	R+R	O+R	R+R	M+R	R+R
Duration of repair, days	55+10	50+10	30+10	30+10	55+10

Note. O, overhaul; M, medium repair; R, routine repair.

The maintenance and repair operations regulations for a turbogenerator set are a component part of the maintenance and repair operations regulations of a power station unit. Therefore, before the regulations are constructed, it is desirable to obtain analogous estimates for the reactor unit and remaining components of the turbogenerator set. Next the rules for selecting among rival versions are formulated, the necessary calculations are performed, and the maintenance and repair operations regulations are compiled.

The problem arose of finding the optimum cycle for scheduled repair of the turbogenerator set in the reactor unit's scheduled repair cycle when the repair cycle for a

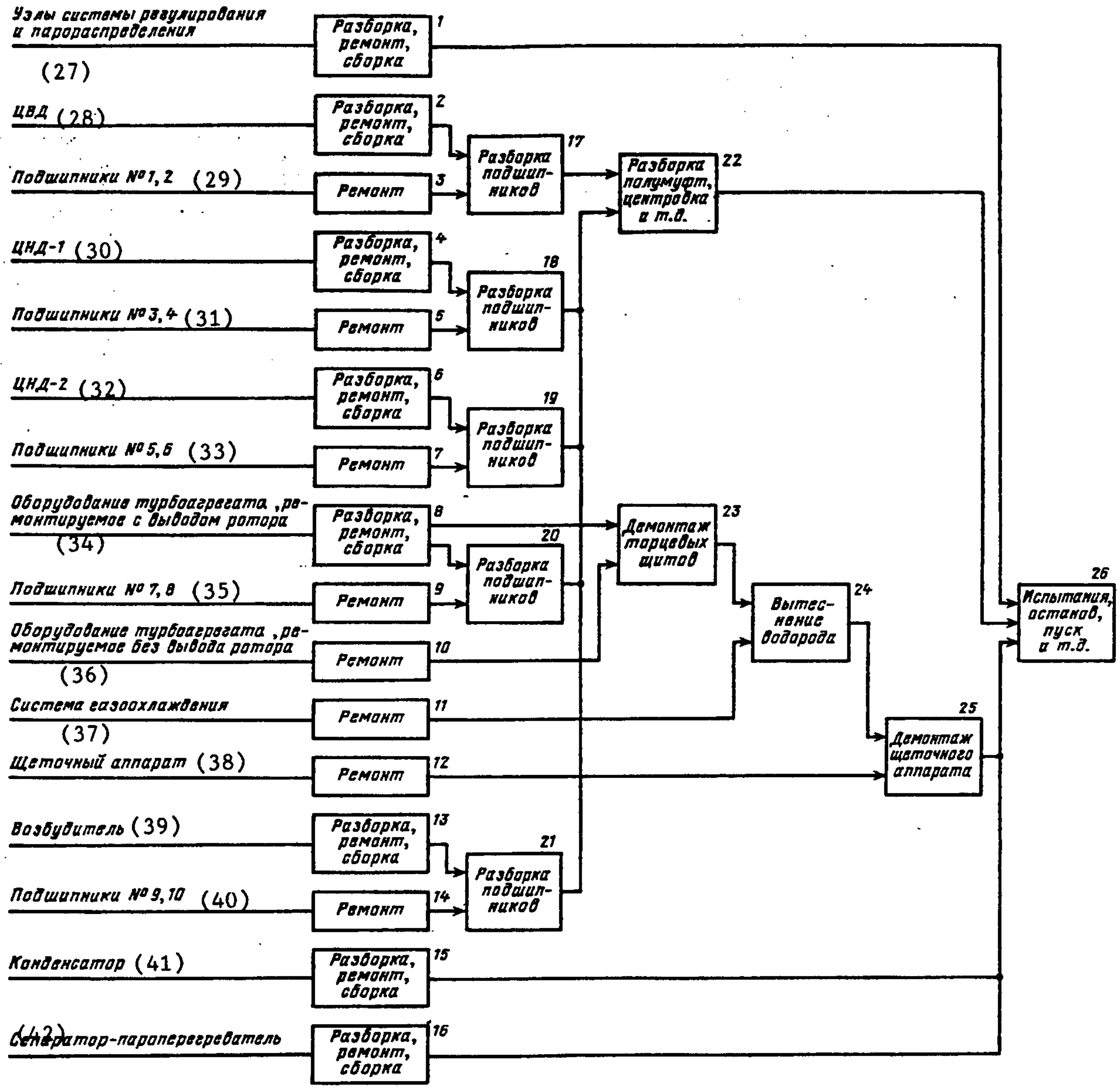

Figure 4. Layout/Block Diagram of Turbogenerator Set

Key: 1. Disassembly, repair, assembly 2. Disassembly, repair, assembly 3. Repair 4. Disassembly, repair, assembly 5. Repair 6. Disassembly, repair, assembly 7. Repair 8. Disassembly, repair, assembly 9. Repair 10. Repair 11. Repair 12. Repair 13. Disassembly, repair, assembly 14. Repair 15. Disassembly, repair, assembly 16. Disassembly, repair, assembly 17. Disassembly of bearings 18. Disassembly of bearings 19. Disassembly of bearings 20. Disassembly of bearings 21. Disassembly of bearings 22. Disassembly of coupling half, centering, etc. 23. Disassembly of face brushes 24. Displacement of hydrogen 25. Disassembly of brush device 26. Tests, shutdown, startup, etc. 27.
Nodes of control and steam distribution system 28. High-pressure casing 29. Nos. 1 and 2 bearings 30. No. 1 low-pressure casing 31. Nos. 3 and 4 bearings 32. No. 2 low-pressure casing 33. Nos. 5 and 6 bearings 34. Turbogenerator set equipment that can be repaired without withdrawing the rotor 35. Nos. 7 and 8 bearings 36. Equipment of turbogenerator set that can be repaired without withdrawing the rotor 37. Gas-cooling system 38. Brush device 39. Exciter 40. Nos. 9 and 10 bearings 41. Condenser 42. Moisture separator/heater

reactor unit was preserved. Research conducted in this direction made it possible to design the structure of the 4-year repair cycle for a unit of the Kola AES that is presented in Table 2.

Equipment	Min. Servicing Frequency, year	Max. Servicing Frequency, year
High-pressure casing	4	6
Low-pressure casing	4	6
Speed governor	4	12
Control valves	0.5	4.5
Bearings	1.5	6

Conclusion

The calculation method proposed makes it possible to construct regulations for the maintenance and repair of the primary equipment of AES so as to ensure the epioptimal loss level while preserving an adequate reliability level.

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UDC [621.311.025:621.039]:621.317.7.001.3

Specific Requirements Imposed for Electric Measuring Equipment Used at AES

907F0119A Moscow ELEKTRICHESKIYE STANTSII in Russian No 9, Sep 89 pp 45-46

[Article by A. L. Voronkova, engineer, and V. M. Mashenkov and V. N. Tolstopyatov, candidates of sciences, under the "Nuclear Power Plants" rubric: "Specific Requirements Imposed for Electrical Measuring Equipment Used at AES"]

[Text] Ensuring the safety and high reliability of modern AES is one of the most important tasks of power generation at the present time. The accomplishment of this problem is largely determined by the reliable operation of the electric measuring equipment and automation equipment included in the automated technological control system of the AES.

In the past few years the organizations of the USSR Ministry of Power and Electrification [Minenergo] and the USSR Ministry of Instrument Making, Automation Equipment, and Control Systems [Minpribor] made specific efforts to improve the electric measuring equipment and computer technology intended for use in automating the power plant control processes. Nevertheless, the failure level of electric measuring equipment remains rather high. This applies to certain types of electric parameter transducers of indicating and recording instruments.

Paying serious attention to the operating safety of AES, in their joint resolution "Additional Measures To Increase the Quality and Reliability of Equipment Created for the Automated Technological Control System of an AES, the Minenergo and Minpribor developed a whole series of measures directed toward increasing the technical level and reliability of the entire list of measuring, control, and computer equipment used at an AES. The technical requirements regarding instruments and automation equipment for nuclear power plants that must be strictly observed by all organizations and enterprises developing, supplying, and operating instruments for AES are specified by this resolution.

These requirements specify the main directions in the technical policy in the creation of instruments. They establish the specifics of the operation of instruments at AES as a function of where they are installed. From the standpoint of operating conditions, depending on the agreement with the user, these instruments should be made for operation in different zones:

—the pressurized zone (zone 1);

—unmanned production sites in the strict mode zone (zone 2);

—semimanned production sites in the strict mode zone (zone 3);

—production sites in the free mode zone (zone 4);

—sites of equipment that is serviced periodically (zone 5);

—sites of control panels (constant presence of personnel) in a free mode zone (zone 6a) and strict mode zone (zone 6b);

—in open air (zone 7).

Higher requirements have also been imposed with respect to instruments' reliability: requirements regarding resistance to the effect of radioactive irradiation and deactivation, seismic effects and vibrations, less need for maintenance and repair, safety technology, marking, and transportation and storage and special requirements regarding designs, metrology, acceptance, and erection and grounding.

For example, instruments intended for operation in the second zone should be fit for operation under the effect of irradiation doses of 10^7 rad over 10 years, devices intended for the third zone should be fit for operation under 600 rads, and those for zone 6a should be fit for 50 rad. Regardless of the place where instruments are located during their operation they should be fireproof, i.e., when any malfunction occurs in the instruments they must not be a source of combustion.

Special requirements are imposed for instruments in the electric power supply section. Unlike the normative documentation of requirements regarding industrywide measuring equipment, the requirements for instruments intended for AES stipulate that they should function as follows: during a change in the network voltage of plus or minus 20 percent over a time up to 100 ms, during interruptions in the supply of electric power of up to 20 ms, and during a change in the AC network's frequency of plus or minus 3 Hz. The instruments should permit manual or, depending on the user's requirements, automatic transition to stand-by power supply from the nuclear power plant's emergency network.

Particular (more specific) technical requirements have been developed (with an allowance for the basic requirements) for individual groups of electric measuring equipment. These requirements regulate the quantitative indicators of the respective parameters, design features, and a number of other specific requirements characteristic for the AES.

We will pause on those distinctive features that essentially differentiate those groups of electric measuring equipment intended for shipment to AES from their analogues intended for industrywide use.

Transducers intended for AES should have machine-oriented monitoring of a break in the incoming circuits. They are generally located in the third, fourth, or fifth zones of the plant, because of which the requirements regarding their reliability indicators are increased (their mean time between failures should be within the range of 50,000 to 150,000 hours). All of the converters are accepted by the USSR State Committee on Supervising Work Safety in Nuclear Power or subjected to special acceptance by the customer, who provides a production run for each converter before acceptance.

High requirements are imposed for the long-range stability of the metrologic characteristics of converters. They should remain within their specified bounds for no fewer than 4,000 hours of continuous operation without adjustment or servicing, and for converters intended for the third zone the requirement is no fewer than 8,000 hours. Maintenance and testing of converters should be conducted no more often than once in 6 months, and converters for the third zone should not be serviced or tested more than once each year.

The requirements for the group entitled analog and digital indicating and recording electric measuring instruments have been extended to a great many instruments: all types of panel indicating and recording instruments and digital panel instruments.

Recording instruments should be capable of peripheral remote automatic or manual start-up and zero-level testing. This group of instruments is installed in AES in zones 5, 6a, and 6b. The mean time between failures should be no fewer than 100,000 hours. Maintenance and verification of the instruments in this group should be conducted no more than once per year. The exceptions are recording instruments that record on coordinate paper, for which refilling the pens and replacing the coordinate paper once per month is permitted. The instruments' design should permit distinct and reliable reproduction of the measurement results, and the angle of the indicating instruments' scale should be no smaller than 240°. For instruments built into mosaic panels the angle should be 90° with a zero readout along the horizontal.

Using glasses made of acrylic plastic or other material capable of accumulating electrostatic charges is permitted only upon special agreement with the customer.

All instruments intended for operation in AES should have a special marking characterizing them as belonging to nuclear power plants.

All new developments of electric measuring equipment for AES are currently being implemented with an allowance for the aforementioned requirements.

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Reserves for Improvement in Internal Combustion Engines

907F0167A Moscow AVTOMOBILNAYA PROMYSHLENNOST in Russian No 8, Aug 89 pp 17-18

[Article under the series title "Engines, an Item of Constant Attention" by candidate of technical sciences I. Ya. Raykov and doctor of technical sciences Ya. A. Spundz]

[Text] Much work involving the design of automotive engines has been and continues to be done at the Moscow Automechanical Institute (MAMI). This involves mainly the training of specialists in two departments, one for automobile and tractor engines and one for gas turbine vehicle engines. Many of the thousands of engine designers have become prominent specialists at the automotive plants, important scientific associates and managers in the automotive industry, in the educational and scientific organizations of the country. Its graduates are also found abroad: in recent years alone, there have been sixty of them from countries of Asia, Africa, and Latin America.

Both departments are now going through a time of change and accelerated progress. Computer equipment has arrived at the auditorium and the laboratory. As early as 1982-1983, a self-standing multistory teaching and laboratory building for internal combustion engines was placed in operation. Specialized auditoriums and classes outfitted with technical learning aids, graphics aids, and full-scale models of the basic parts and subassemblies of new and future engines have been organized. New laboratories have modern test stands and their own computer station, which the students use extensively in their regular studies and graduation projects. A mobile platform with an array of Soviet instruments has been created for determining the basic components of exhaust gases. The TsAM PU-10 universal vibration-loading machine has been installed and set in operation, designed to conduct scientific investigations and laboratory educational courses on engines, and so forth.

The engine departments of the institute are training engine designers and researchers with the use of the modern engineering base of the sector. For example, in 1985, the department of automobile and tractor engines opened a branch at the Scientific Automotive Motor Institute (NAMI) and on this footing began to train engineers able to work with computer-aided design (CAD) systems. A complicated educational program in the mechanical design of engines was developed for them and they take additional lectures in applied mathematics (theory of elasticity, finite element method, etc.). Branches have also been organized at the Automotive Plant of the Lenin Komsomol (AZLK) and in the scientific research institute of automotive tractor materials. One of these is specialized primarily in engine testing, the other in the use of ceramics in automotive engine design.

An important area of activity of the engine designers of the MAMI is scientific research and development of new designs for automotive transportation. And a lot has been accomplished here.

Thus, under the leadership of G. P. Pokrovskiy, many problems have been resolved in the use of electronics to control the devices which reduce toxicity of exhaust gases. In particular, an engine control system using the criterion of engine knock has been created (USSR patent 907291), which adapts itself to the specific conditions. While maintaining the customary level of compression, this makes it possible to use gasolines with 5-7 less octane units, without the risk of worsening the ecological characteristics of the exhaust (the system has been handed over to the NIIAE).

Also of great scientific and practical interest is the development of a thermoanemometric film gage (Fig. 1, not reproduced) for the mass flow rate of air, designed for the electronic fuel dispensing and ignition timing control systems. It is much more reliable and accurate than the devices formerly used for such purposes. Also worthy of note is a device (USSR patent 717392) for testing a forced idling economizer, which has been adopted by the Moscow Carburetor Plant.

The group of Yu. N. Nikitin is engaged in modernization of automotive and tractor Diesels (improving the cylinder-piston and crankshaft- connecting rod groups). They have developed and introduced a technique and created a system (Fig. 2) for measuring the thickness of the oil layer in the couplings of the piston-cylinder group and in the bearings of the crankshaft-connecting rod mechanism. Such measuring systems have already been handed over to the YaMZ, the KamAZ, and the Volgograd motor plant. The engine building plants have been issued specific recommendations for improving the hydrodynamic characteristics of cylinder-piston-piston ring couplings, those in the crankshaft bearings, and so forth. As a result, the parts of these couplings have been modernized at a number of plants. For example, a set of rings and pistons of improved profile has been introduced at the Vladimirsk tractor plant, a connecting rod of better reliability at the KamAZ, an optimal regime for preparing engines to take up load at the YaMZ, and so on.

The group of G. N. Rytvinskiy is occupied with problems of gasoline engine pumps. In particular, in 1984 he built a mockup of a rotary pump (Fig. 3) for the AZLK-412 engine and worked up the documentation for a modification of the carburetors K-126 and DAAZ-2106, designed for supercharged engines. Mockups of the carburetors were constructed.

Without doubt, the work of the group of A. V. Kostrov on improving the design and enhancing the reliability of piston gasoline engines is of great practical significance. Investigation of the temperature deformations led to an

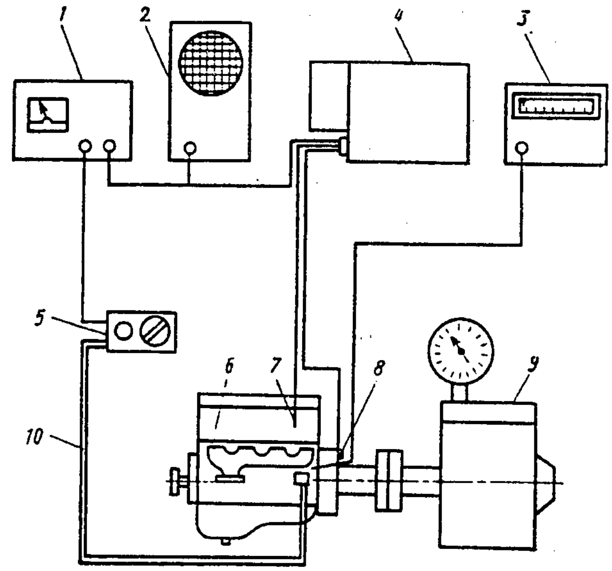

Figure 2. System For Measuring the Thickness of an Oil Layer

Key: 1. PITS-MAMI amplifier 2. Cathode oscillograph 3. Potentiometer 4. Electromagnetic oscillograph 5. Multiposition switch 6. Motor 7. Admission time marker 8. VMT marker 9. Brake 10. Cord of wires from sensors

oval barrel-shaped profile of the apron with a temperature-regulating insert, almost ideally suited for quick fitting to the cylinder face. The piston has already been introduced in the prechamber-igniter engines ZMZ and is being introduced in the ZMZ-24 and ZMZ-53. During the course of the investigations, a technique was created

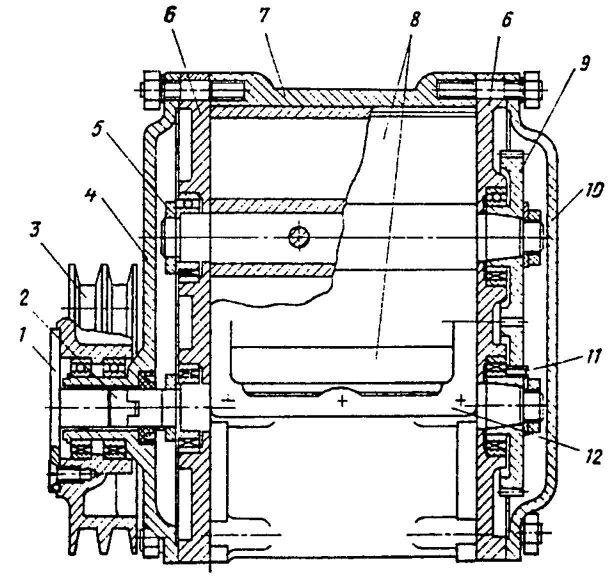

Figure 3. Positive-Displacement Rotary Pump

Key: 1. Plate 2. Bearing 3. Pulley 4 and 10. Covers 5. Shaft nuts 6. Side walls 7. Housing 8. Rotors 9. Synchronizing gear 11. Set screw 12. Connection flange

to test the pistons of a carburetor engine (USSR patent 1008639). The motorless stand (Fig. 4), designed and built by V. P. Belov (USSR patent 1012066), allows faster investigation of the thermal stability of pistons.

At the department of automotive and tractor engines, with collaboration from the departments of metal

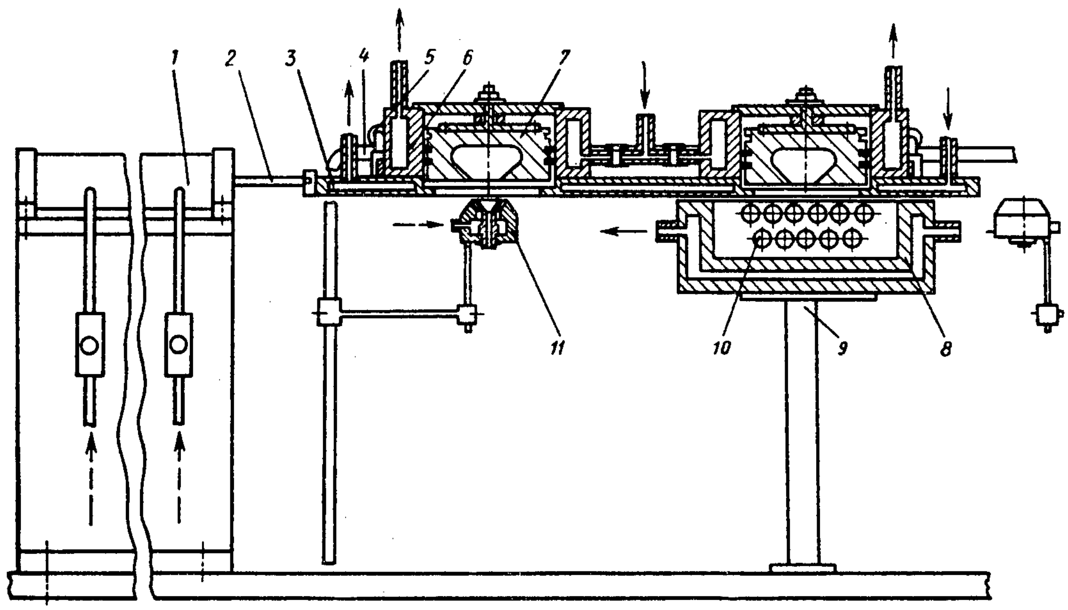

Figure 4. Motorless Stand for Testing the Thermal Stability of Pistons

Key: 1. Pneumatic cylinder 2. Rod 3. Carriage with cooling jacket 4. Rail 5. Roller 6. Sleeve with cooling jacket 7. Head of piston being tested 8. Heater 9. Stand 10. Halogen bulbs 11. Injector working by pressure, foundry production, and materials science, a complex of work is being done to extend the lifetime and improve the quality of pistons. A team is working intensely on the creation and mastery of press-forged pistons for automobile and motorcycle engines (along with the KamAZ, ZMZ, Kostrovskiy "Motordetal", and other plants): trial production sections have already been organized at the VNIImotoprom and the Motordetal plant of Kostroma.

Since 1988, both engine departments of the institute have switched over to training of specialists of a broader profile, able to develop not only the traditional piston automotive and tractor engines, but also promising combination-type (turbine-piston) adiabatic power plants, combinations of internal and external combustion engines, and various kinds of heat recuperators. Special attention is to be given to problems of ecology.

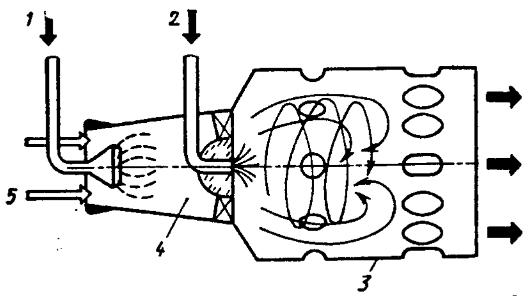

Figure 5. The Low-Toxic Combustion Chamber of the Automotive Gas Turbine Engine

Key: 1. Main supply of fuel 2. Supply of fuel through injector during operation 3. Combustion chamber 4. Evaporator- homogenizer 5. Supply of air to combustion chamber through evaporator

The department of transportation gas turbine engines is one of the leaders of progress in the theory and practice of successful development of original Soviet automotive gas turbine engines, as well as the creation of Diesel turbocharging systems. Its specialists have proposed a new method of profiling the rotors of centrifugal compressors and radial turbines (group leader S. V. Michalev). Together with the Gorkiy automotive plant, they have established the feasibility of a fundamentally new layout of a multiple-duty automotive gas turbine engine (AGTD) that has set the pace for the development of such engines. (The validity of the choice was confirmed much later by experiments in the West.) Together with this same plant, the department has investigated and created low-toxic combustion chambers with preliminary preparation (homogenization) of the fuel mix. The toxicity of the emissions of AGTD with such chambers has proved to be (in conformity with the theory) an order of magnitude lower than that of piston engines. Moreover, it has become clear that the AGTD may be the first practically nontoxic thermal automotive engine. In recent time, research and development have been carried out on several promising schemes for intermediate cooling of the compressed air in the turbocharging systems of Diesels (Yu. S. Kustarev, Yu. I. Freyman, V. G. Belkevich). An original fan has been designed, the characteristics of which may substantially improve the efficiency of the engine cooling system. Entirely new areas of work are combustion chambers for so- called energy-accumulating substances, as well as the use of high-temperature ceramics in the turbocharging systems of Diesels and small AGTD with ceramic flow section. The promise of the latter area of work is shown by such facts as the following: Japan and the USA have already created models of small AGTD with ceramic flow section, while the pan- European scientific program Eureka intends to create such for an ecologically clean "car of the year 2000." In 1988 the department began training engineer specialists in the use of ceramics in automotive engine design.

As we see, the members of the engine departments of the MAMI have achieved rather significant results in their work on problems of engine construction. But these results would have been even more tangible had the Ministry of Automotive Agricultural Machinery assisted them, at the right time and in the proper amount, especially in the acquisition of modern computer equipment. For the lack of this not only holds back the pace of scientific research, but also (objectively) lowers the level of training of the engine designers. Both factors represent an immediate loss to the economy.

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Composites in the Structures of a New Generation of Engines

907F0167B Moscow AVTOMOBILNAYA PROMYSHLENNOST in Russian No 8, Aug 89 pp 19-20

[Article by doctor of technical sciences G. M. Volkov and candidates of technical sciences V. I. Panin and G. N. Rytvinskiy]

[Text] For long years the design of engines has made exclusive use of metals and their alloys. However, in the recent decade, nontraditional materials—nonmetallic and composite—have started to be adopted. They make it possible to solve problems that have long plagued the industry—how to improve the fuel economy, extend the lifetime, and reduce pollution of the environment by automobile engines.

Thus, the fuel economy is improved by reducing the mechanical losses in frictional couples, by increasing the energy intensity of the process of burning the fuel, by recuperating the energy of the spent gases, and by reducing the weight of the engine itself; the lifetime is extended because the new materials are more wear resistant and stand up better to alternating loads, high temperatures, and so on.

Yet the new materials are generally more expensive than the traditional ones, and the gamut of their physico-mechanical properties is more narrow. Therefore, it is advisable to use them to replace traditional materials where they are most advantageous. Just where this is, the specialists of the MAMI and VNIImotoprom have sought to determine.

The most energy-intensive friction contact is observed in the bearings of the crankshaft of an internal combustion engine. The majority of multiple cylinder engines, for technological considerations, employ sliding bearings that work with hydrodynamic lubrication. But in practice one may not rule out a short-term operation of such bearings in conditions of dry friction. Hence, the frequent instances of "seizing" and scratching of the antifriction layers based on metallic alloys. Consequently, it is sensible to employ the new materials if they allow the frictional assembly to operate under extreme conditions, i. e., if they have a sufficiently low coefficient of friction under short-term dry friction and exhibit no tendency to plastic deformation under short- term load. It would also be good if the thermal conductance of the antifriction material surpassed that of the oil layer on its working surface: this would make it possible to employ less viscous oils, which would reduce the hydrodynamic losses in the zone of friction and during the circulation of the oil in the lubrication system of the engine. (Incidentally, the use of composites with a polymer matrix in crankshaft bearings is problematical precisely on account of their low thermal conductance.)

Without doubt, ceramic rolling bearings that can work without forced lubrication are of great interest. Especially since the complication which this introduces into the technology of fabrication and assembly of the crankshaft-connecting rod mechanism on a compound crankshaft may be offset by increasing the period of service of the frictional unit between repairs, and also by technological and operational advantages of dispensing with liquid lubrication.

The connecting rod is one of the most stressed parts of the internal combustion engine. The nature of its loading is such that a composite will serve only if reinforced with fiber fill, e. g., aluminum with continuous fibers (based on organic and carbon plastics, corundum or carborundum) or with high-strength steel wire. In this case, the weight of the connecting rod is reduced by 30% (composites with steel reinforcement) or even by 50% (composites with polymer matrix), which accordingly diminishes the dynamic loads in the crank mechanism and the engine vibrations (noise).

The connecting rod (Fig. 1, not reproduced) is made of composite materials and has an integrated crank head. The reinforcement which braces the rod is prestressed with a force that exceeds the maximum tensile stresses during operation. The shaft of the connecting rod should have bulk reinforcement, and the modulus of elasticity of its material should surpass that of the material of the surrounding hinge. (Figure 2 [not reproduced] presents a version of the rod with removable crank head made of composite).

The parts of the cylinder-piston group are subjected to the action of large thermal, mechanical, and frictional stresses, the magnitudes of which largely depend on the mass of the parts, or rather the inertial forces. In order to diminish these forces, the mass of the moving elements should be as small as possible. And composites reveal ample prospects here. For example, the piston bottoms may be reinforced with inserts of composite material with metallic matrix, reinforced with discrete fibers. The matrix is aluminum-based piston alloy, which simplifies the technological integration of the insert and the piston metal during the liquid phase step of the manufacturing process. The reinforcement is with discrete fibers, which increases the thermal cycle endurance by a factor of 4-5. As a result, the temperature deformations of the piston bottoms are reduced and stabilized, thanks to which the volume of the dead space of the combustion chamber is reduced and, accordingly, the toxicity of the exhaust is diminished. The groove for the first compression piston ring is given high resistance to wear.

New materials make it possible to have not only a piston with inserts in its bottom, but also an entire compound piston (Fig. 3, not reproduced) with significantly different properties for its head and skirt. The latter, made of composite with polymer matrix, is an advantage both in terms of the piston mass and the noise level of the engine. The composite makes it possible to reduce the initial adjustment spacings for the piston in the cylinder, thus reducing the dynamic loads during its reversal. The rubbing forces of the piston against the walls of the cylinder can be lessened by using materials with antifriction properties. This, in turn, allows a substantial decrease in the required rate of sprinkling the cylinder face, even to the extent of total elimination of liquid lubrication, which thus reduces the specific stress on the cylinder face from the oil control ring, the scorching of the oil, and the toxicity of the exhaust.

Moreover, with materials having excellent antifriction properties and low coefficient of thermal expansion (polymer-ceramic type), it is even possible to consider a ringless, labyrinth seal of the piston clearance, which may drastically reduce the mechanical losses in the engine.

Nonmetallic and composite materials in the parts of the gas distributing mechanism, for example, in the cam and follower disk assembly, also reduce the mechanical losses. At the same time, the reliability and wear resistance of these parts are enhanced. But the assortment of parts of the gas distribution mechanism for which wear-resistant composite and ceramic materials are recommended is not limited to this. They can also be used to make the cam followers, the disks of the followers, the valves, the guide sleeves and seats of the valves, and the cams of the distributing shaft. (In the latter case, a new design configuration of the distributing shaft is needed: it must be compound, consisting of a hollow shaft with cams attached to it.)

All of the above is not just potentialities. The first models of cam followers of composite material reinforced with discrete carbon fibers have already been created and tested; cam follower disks have been made of ceramics (Fig. 4, not reproduced); spring plates have been made of polymer composite. As a result, the mass of the moving parts of the gas distribution mechanism of the engine has been reduced by 15%.

Composites with polymer matrix are irreplaceable as a means of reducing noise pollution of the environment associated with the running of an engine. The potentialities here may be judged from the following example: replacement of the aluminum crankcase pan with a composite having a polymer matrix, according to Japanese data, reduces the noise level of the engine by 4 dbA. Composites can be used not only for the crankcase pan, but also for such elements as the covers of the gas distribution mechanism, the actuator of the distributing shaft, the crankcase, and other body parts (Fig. 5, not reproduced).

On the whole, an analysis performed by the specialists of the VNIImotoprom and MAMI has revealed that composite materials and construction ceramics have reached such level of development as makes feasible the creation of a new generation of automotive engine with less mass and better economy, toxicity, and noise parameters. But this requires, first, a close coordination among the processes of design of the parts, construction of the composite material, and the technological process of its fabrication. And second, we require methods for design of an engine made of composite materials and, thus, the underpinning of such methods, i. e., extensive experimental research, conducted on a modern scale.

UDC 621.43.001.63

For the Sake of Progress in Engine Design

907F0167C Moscow AVTOMOBILNAYA PROMYSHLENNOST in Russian No 8, Aug 89 pp 23-25

[Article with a prefatory note under the "The MAMI Graduates Speak" rubric by Ye. V. Shatrov]

[Text] The author of the following article is candidate of technical sciences Ye. V. Shatrov, deputy director of the NAMI for scientific affairs. He is one of those who are articulating the technical policy of the sector in the field of automotive engine design, laboring long and productively over the creation of new generations of engines and their modernization, over the use of alternative fuels, and over the introduction of scientific research findings in practice. His enthusiasm for internal combustion engines began during his studies at the MAMI. Thanks in no small measure to the mastery of the scientists and teachers at the department of automotive and tractor engines, worthy scientists and technologist I. M. Lenin, professors K. G. Popyk and K. I. Sidorin, and many others.

Ye. V. Shatrov still keeps his ties with his school. He is a constant participant in the scientific conferences and seminars held here, for many years he has lectured on internal combustion engines at the GEK, and like the other specialists of the MAMI he has taken a hand in a considerable portion of the research projects of the NAMI.

Engine design is a critical area of work occupying the scientists and specialists of the NAMI. The main areas of such work are the protection of the environment, economization of petroleum motor fuels, lower metal content of internal combustion engines, longer lifetime and troublefree operation. And quite a lot has been done in recent time on each of these.

Thus, in order to solve the problem of reducing harmful emissions into the atmosphere, the specialists of NAMI together with specialists from other research institutes, automotive plants, and technical colleges as far back as the early seventies created a series of government and trade standards placing limits on such emissions with the exhaust gases. Characteristically, the standards called not only for limiting the quantity of toxic substances emitted, but also gradually tougher requirements in the future term.

For example, they called for reducing the emissions of carbon monoxide during the idling of engines over a nine year period (1971-1980). The requirement was met. Moreover, by 1980 an automobile during movement was required to have 45% less emission of carbon monoxide and 25% less hydrocarbons than in 1975. In the end result, the emissions of carbon monoxide of an automobile weighing up to 3 tons were reduced to a third during this period, that of hydrocarbons to a half, and that of nitrogen oxides by a factor of 1.5. This was accomplished primarily by selecting an array of antitoxic devices for each model of automobile produced by the industry, up to a total weight of 3.5 T.

During this period, carburetors with electronic control system for the supply of fuel during idle performance and nontraction duty, automatic starting and preheating, pneumatic actuation of the secondary chamber, and automatic inlet air preheating, and systems for recirculation of exhaust gas and trapping of fuel fumes were developed.

In recent years, research, design, and modification projects have been carried out with the research institutes and plants of the sector to create oxidative and bifunctional exhaust neutralization systems (ENS) on the basis of a feedback sensor (λ-probe), along with a multifunctional microprocessor engine control system.

No less acute that toxic emissions is the problem of noise created by automobiles: in the medium and large cities this reaches 70-84 dbA and persists for a steady 12-16 h per day, while the maximum permissible levels of noise are 84-92 dbA (thus, they have already been virtually reached), and the sanitary standards are no higher than 60 dbA.

The NAMI has become involved in the nationwide program "High-speed, ecologically clean transportation," which envisions creating automotive transport systems having excellent ecological properties and less fuel consumption than the present engines.

The studies carried out in recent years have already made it possible to reduce such consumption of series produced engines with spark ignition by 4-7%. For example, realization of the work process, developed by specialists of the NAMI, with swirl movement of the cylinder charge in the ZIL and ZMZ V-shaped gasoline engines has reduced the operating fuel consumption in trucks and buses by 6-8%, while the pear-shaped combustion chamber (Fig. 1) of the UMZ engines has reduced it by 4-5%. But by 1995, the fuel consumption will have been reduced by a total of 15%, compared to 1985.

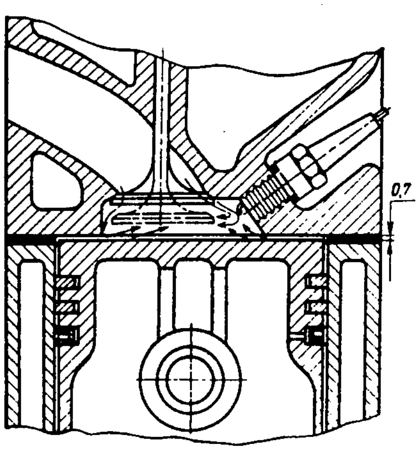


Figure 1.

The theoretical projects, the existing scientific groundwork, and the results of experiments performed by the NAMI show convincingly that there is every possibility of creating a working process that substantially enlarges the range of effective leanness of the fuel and air charge (as much as α=1.3-1.5) and increases the degree of engine compression to 10-12 without raising the requirements on the octane number of the fuel.

Structurally, this will be accomplished, first, by developing multiple- valve gas distribution systems which regulate the turbulence of the charge at the inlet of the engine cylinders (the working mixture under low and medium load and at low speed of turning of the crankshaft is admitted through one valve, in other situations through two valves). A second realistic chance for improving the fuel economy and energy performance of engines is supercharging (using a turbine compressor or power-operated pump).

Both lines are beginning to materialize: the NAMI together with the plants is already developing a new generation of gasoline engine for the future automobiles AZLK, GAZ, ZAZ, and "automobiles of the year 2000." A third avenue is also being pursued—the use of electronics, especially integrated microprocessor engine control systems.

These are what may be called the traditional approaches, even though they are being carried out, of course, with new technology and theoretical underpinnings. But the NAMI is also occupied with entirely new problems. In particular, engines running on fuel of nonpetroleum origin—alcohol (methyl and ethyl), hydrogen or a mixture of this with gasoline, biogas, various synthetic and other kinds of so-called alternative fuels. It is not only occupied by this work, it is also the leader (since the mid-seventies). For example, the work on the use of hydrocarbon (propane-butane) and natural (methane) combustible gases, which (it has already been proven) most fully assure the utility features of automotive transportation, and not only free up the petroleum fuels, but also cut down on operating costs to maintain the automobiles (thanks to less expense on fuel, longer engine life, reduced consumption of motor oil, etc.).

Already today, designs of gas tank apparatus have been created for 32 models of truck, car, and bus. There is also such apparatus for Diesels, working with a gas-Diesel cycle. The apparatus is standardized and can be installed in all gas-Diesel automobiles and buses—the BelAZ, GAZ, ZIL, KamAZ, MAZ, KrAZ (e. g., the gas-Diesel tractor KrAZ-258 in Fig. 2 [not reproduced]), LAZ-4202, Ikarus-280. Today, the KamAZ (as our journal has already reported) manufactures six modifications of gas- Diesel automobiles, which preserve all the energy characteristics on the level of the original Diesel motor, but reduce the Diesel fuel consumption (by 80%), the smoke content of the exhaust (to a third), and the noise level (by 3-4 dbA).

Thus, the NAMI working with the plants of the sector has solved, both theoretically and practically, a major economic assignment, given to the sector for the Twelfth Five Year Plan—the replacement of petroleum fuel with gaseous fuel in automotive transportation.

The possibility of using methyl alcohol, hydrogen, and mixtures of these with gasoline is also being studied. In particular, the scientific foundations have been worked out and the fundamental possibility has been demonstrated for converting automobiles to run on alcohol and hydrogen; and models of such automobiles have been created, built, and experimentally checked out on the test stand and on the road. Furthermore, industrial lots of ZIL trucks and RAF microbuses have already been produced. Extensive operational testing of these reveals that the addition of 5% methanol to gasoline preserves the power, economy, and ecological parameters of the engine, but makes it possible to run on gasoline with a lower octane number and replace ethylated with nonethylated gasoline; the mixture of gasoline with 15% methanol and 7% isobutyl alcohol, added as a stabilizer, improves (with the proper carburetor adjustments) the dynamic qualities (by 6%) and the power indexes (by 5%), while lowering the overall toxicity of the exhaust gas (by 25%). The consumption of gasoline is reduced by 14% in this case.

The NAMI has also created and carried out practical verification of engine supply systems using pure methanol and demonstrated the possibility of using gasoline-methanol mixtures and pure methanol in all automobiles of the presently available assortment in the country.

Studies are nearly finished on the use of mixtures of hydrogen with gasoline as a fuel; original systems have been designed to supply engines with hydrogen fuel and to store the hydrogen in the automobile. It has been established, for example, that RAF buses (Fig. 3, not reproduced), operating on gasoline-hydrogen mixtures, produce 17 times less emission of carbon monoxide, 5 times less nitrogen oxides, and 30% less hydrocarbons. The hydrogen consumption in this case is 1.8 kg/100 km, which is equivalent to 6.7 kg of gasoline. Consequently, the actual savings of gasoline by using gasoline-hydrogen mixtures is 55%.

Thus, it has been proven that the clear preference should be given to hydrogen as a motor fuel in developing ecologically clean automobiles.

Of course, unsolved problems remain in the area of use of alternative fuels. But what is important is that the specialists of the NAMI have determined the most logical sequence for their solution. This sequence is: production of lightweight (not more than 30 kg) high-pressure (20 MPa or 200 kgf/cm^2) tanks for compressed methane; development of ecologically justified and reliable cryogenic systems for storing liquid hydrogen and methane aboard the automobile; expansion of the fundamental research into the processes of inflammation and combustion of alternative fuels; improving the reliability and lifetime of the gas tank equipment.

It should be pointed out that the weight, the reliability, and the lifetime are areas of investigation of the specialists of the NAMI not just in respect of gas tank equipment. An example of this is the work on comprehensive protection of engines against abrasive wear: creation of an array (Fig. 4, not reproduced) of filtering elements to clean the air, the oil, and the fuel, and in future—use of polymer, composite, and ceramic materials in the structures. That which has already been accomplished speaks for itself: in recent years, the weight of the engine has been reduced by 40%, the mechanical losses by 15-20%, and the engine life increased by a factor of 1.5-2.

It may be said that the NAMI has expanded considerably the scale of the work on development of gasoline engines with cutting-edge technical solutions, which have been introduced not only into the existing designs, but also in fundamentally new developments. The goal is to create engines of a new generation with indexes on a par with the worldwide standard as predicted for the period of 1995-2000, to verify selected design and technology ideas on the test stand and under road conditions, and to introduce them one element at a time in the engines being prepared for production in the thirteenth and subsequent five year periods. These ideas involve operational processes with layering and swirling movement of the fuel and air charge in high-turbulence combustion chambers; profiled mix and air supply channels; higher degrees of compression; superlean working mixtures; multiple-valve gas distribution systems; engines with variable work volume and axial arrangement of cylinders; supercharging by means of turbine compressor, power-operated pump, or both; multifunctional microprocessor systems for control of engines with carburetor type fuel supply and injection; alternative fuels; designs using polymer, composite, and ceramic materials, and so forth.

As we see, the volume and trend of the work are rather broad. And so are the results. And much of the credit goes to the graduates of the Moscow Automotive Mechanical Institute, now working within the NAMI: for it is here where they acquired the rudiments of fundamental knowledge and developed not only the mind set, but also (it can be said) the habit of work, or research, and of taking a scientific risk.

Even now, the engineers have not lost scientific links with their "alma mater"—together they are carrying out a broad range of research projects. For example, the creation of parts for automobile engines of composite materials and the choice of technologies for their fabrication; the study and development of the theoretical foundations of design of bimetallic pistons with reduced friction and supply systems for future piston engines; the practical introduction of CAD, computer- aided strength analysis systems, and accelerated testing methods. In this area, a branch has already been created on the grounds of the NAMI, where students are studying the rudiments of design and the CAD hardware, interactive systems, computer graphics, and information processing. Not without the involvement of the scientists of the MAMI, the volume of fundamental research is increasing and the equipment base is being renewed, which with the help of laser, optical, and other modern registration techniques will study the features of development of the processes of inflammation, combustion, the gas dynamics of the fuel and air charge, heat transfer, and other processes taking place in the engine cylinders. And the MAMI will also train engineers with such grounding in the immediate future.

The State Association of the Construction Materials Industry (Soyuzstroymaterialov) Reports

907F0246A Moscow STROITELNYYE MATERIALY in Russian No 2, Feb 90 pp 2-3

[Unattributed article]

[Text] The State Association of the Construction Materials Industry (Soyuzstroymaterialov) was formed on proposal of the labor collectives of the enterprises and organizations of the construction materials industry in accordance with the resolution of the USSR Council of Ministers "On the organization of concerns and a state association of the construction materials industry." It is an independent economic- production complex, pursuing its activity on behalf of the government and the enterprises and organizations included in its constitution on a basis of further democratization of management, expansion of cost accounting, and development of self financing and self management of the labor collectives.

The state association Soyuzstroymaterialov is made up of the concerns "Tsement," "Asbest," "Asbestotsement,-" "Tekhsteklo," "Stromteplomash," "Spetszhelezobeton," "Soyuzmineral," the Scientific and Engineering Center of the Construction Materials Industry (Strominnotsentr), and also the entities which service this sector: the All Union Association "Stromsyrye," the Commercial Development Bank of the Construction Materials Industry (Strombank), the All Union Foreign Trade Association "Stroymaterialintorg," the Personnel Training Center of the Construction Materials Industry and the Machine Building Sector, the Construction and Assembly Trust, the cost-accounting commercial company "Komfort," the Central Headquarters of Paramilitary Mine Rescue Units, and the "Khozbytobsluzhivaniye" company.

Together with the concerns and the Strominnotsentr, the association brings together more than 200 enterprises and organizations in the production of cement, asbestos, asbestos-cement products, special and technical glass, heating fixtures, domestic appliances and machine products, special ferroconcrete items and structures, in the mining and production of non-metal ore materials, all also specialized scientific research, design and development, trouble-shooting, construction, geological prospecting, and several other organizations. The concerns, enterprises, and associations making up the association retain their economic independence, and the relations among them are framed on a strict contractual basis.

The association may include, as full participants, other economic associations, organizations, and enterprises; and also, in the capacity of associate members acknowledging the charter of the association but without changing their administrative affiliation, regional structural subdivisions in the form of the construction materials ministries of the Union republics, territorial and sectoral concerns, associations, enterprises and organizations, as well as the enterprises and organizations of other sectors of the economy that are interested in its activity, including joint ventures and organizations with foreign companies.

The association will interact with the central, republic, and local bodies of economic management within the scope of the authority granted to it by the concerns and organizations making up the association and the authority transferred to it by the central bodies of state control. In respect of its constituent concerns, enterprises, and organizations, it is an executive body of state control as regards the production and distribution of supervisory data, state contracts, limits, economic standards, and other indexes to be established by the bodies of the state control.

The state association Soyuzstroymaterialov is entrusted with the responsibility of meeting the demands of the economy for products in the assortment that has been assigned to it and of promoting the sector. Accordingly, the chief duties of the association are:

to elaborate a Union-wide strategy of development of the production of construction materials and articles and the engineering equipment for these purposes, and to coordinate its practical implementation;

to organize the development and coordinate the implementation of state scientific and engineering programs as regards the construction materials industry and vital interbranch and sectoral programs to work on priority tasks in the development of the sector, to hasten its pace of modernization, to create new kinds of engineering equipment and machine systems for the construction materials industry, new and effective kinds of products, improved and ecologically cleaner technological processes;

to provide for comprehensive development of the raw material base in the sector, to define steps for rational utilization of natural resources, waste products, and by products from other sectors of the industry in the production of construction materials;

to organize the development, along with other concerned organizations, of fundamentally different kinds of raw materials and expendables for a radical improvement in the quality of products of construction purpose;

to work out the lines of an investment policy ensuring a balanced and proportional development of all subsectors of the construction materials industry and the machines needed for these purposes, to situate the production in a rational manner among the Union republics and regions of the country through coordination with the Union republics;

to develop a system of economic and legal measures encouraging the associations and enterprises of the sector to expand the production of progressive and very scarce construction materials and articles and the equipment for their production and to improve the quality of the products;

to organize and supervise the process of price formation in the construction materials industry and the machine building of the sector, to develop and evaluate wholesale price lists for the most important kinds of construction materials and articles in accordance with the government policy in this sector;

to render to the concerns, associations, enterprises, and organizations technical, methodological, consultative, and other aid in the elaboration of economic standards, in the prosecution of their production activity, in the implementation of development programs, and in the adoption of modern forms of organization of the management, labor, and production;

to conduct studies, together with interested bodies, of the demand of the population for the products and services of the sector;

to work out proposals and implement measures to develop economic and scientific-technical contacts with foreign nations;

to supervise the sector system of personnel training and continuing education for managerial and technical-engineering workers in the construction materials industry and the machine building of the sector;

to study, generalize, and disseminate progressive experience, to organize the system of information flow in the sector;

to develop the warranty services of the concerns, associations, and organizations of the sector via an expanded network of specialized, cost-accounting organizations;

to organize the material and technical support with centrally allocated resources, equipment, spare parts, and to improve the system of material and technical supply and transportation haulage;

to develop and approve the balance sheets and plans of distribution of products in the assortment as defined by the USSR Gosplan and the USSR Gossnab.

The association pursues its economic-production and foreign trade activity in the entire territory of the USSR in accordance with the legislation of the Union of SSR and the Union republics, and in the territory of other countries in accordance with the prevailing laws and international agreements.

The USSR Gosstroy is entrusted with the coordination of the activity of the Soyuzstroymaterialov association.

The aforesaid resolution of the Council of Ministers determines that the executive management body of the association is the board [council], made up of executives of the concerns, associations, enterprises, and organizations.

At the organizing conference, held on 24 Nov 1989, P. P. Zolotov was elected chairman of the board of the state association Soyuzstroymaterialov, and Yu. T. Komarov, N. I. Makarov, and A. F. Poluyanov vice chairmen.

At the first meeting of this board, the administrative officers of the association were chosen, viz., P. P. Zolotov, chairman, V. I. Kushchidi, first vice chairman, N. F. Ryzhov, V. Ya. Serebrennikov, B. G. Slavtsov, Ye. V. Filippov, vice chairmen. V. Ye. Avdeyev, V. Ya. Zhuk, V. N. Kalinin, M. I. Kotov, V. I. Paramonov, A. V. Razumovskiy, V. Ya. Sidorov, V. I. Chirkov, and N. A. Shadrin were selected members of the board with deciding vote, and P. P. Vakulenko, Yu. M. Vinogradov, V. V. Devyatov, B. M. Tester, and I. S. Tsvetkov members of the board with advisory vote.

Further details may be obtained from: 121908, Moscow, G-19, prospekt Kalinina, 19, State Association Soyuzstroymaterialov, telephone 202-36- 56.

UDC 621.661.6

New Tool Materials

907F0225A Kiev TEKHNOLOGIYA I ORGANIZATSIYA PROIZVODSTVA: NAUCHNO-PROIZVODSTVENNYY SBORNIK in Russian No 1, Jan-Mar 90 pp 5-8

[Article by G. G. Karyuk, doctor of technical sciences]

[Text] The chief trend discernible at present in metal working is the transition from discrete processes to continuous ones. New tool materials are destined to play a critical role in the implementation of new machining technologies.

The Institute of Problems in Materials Science of the Ukrainian SSR Academy of Sciences has done much work in the creation of progressive tool materials with high utility features.

Thus, nontungsten hard alloys based on titanium carbide of type KTS are 2-2.5 times lighter than alloys of the group VK, possess excellent hardness, wear resistance, and mechanical strength. They may be used in place of standard hard alloys of group VK in the fabrication of tools for cutting of metal.

The high wear resistance of the new alloys affords the possibility of their use for production of parts exposed to intense wear. These alloys function well in conditions of low-cycle fatigue under high pressure.

The new alloys of type KTS are obtained from mixtures of powders (intensified wet grinding of the initial components) by pressing with subsequent sintering in vacuum.

The basic physico-mechanical properties (hardness, strength in bending and compression, elastic characteristics) of hard alloys of type KTS, alloys T15K6, VK8, and the nontungsten hard alloy TN20 are about the same.

In resistance to scaling, alloys of type KTS are greatly superior to standard alloys of group VK. The thin oxide film forming on the surface of the former plays the part of a solid lubricant in the process of use of the tool at high temperatures. As a result, the alloys possess a low coefficient of friction and high resistance to wear.

Alloys of type KTS are distinguished by excellent cutting properties in the machining of structural, alloy steels, nickel and aluminum alloys (Table 1). Thus, the durability of the alloy KTS-2M during lathe work of the aforesaid materials is 1.5-3.0 times higher than that of tungsten-containing hard alloys. The surface of the part being machined in this case has less roughness than that of a part worked with tungsten-containing alloys, owing to the slight tendency of alloy KTS-2M to diffusion and its low coefficient of friction.

Table 1. Recommended Cutting Regimes for Lathework With Hard Alloy KTS-2M Tipped Tools

Material machined	Cutting regime			Coefficient of relative durability		
	v, m/min	S, mm/rev	t, mm	VK8	T15K6	KTS-2M
30KhGSA	80-150	0.20-0.6	2.0-4.0	—	1	3
40KhN2MA	60-80	0.20-0.4	2.0-4.0	—	1	2
50N	100-130	0.10-0.3	1.0-3.0	1	—	1.5-2.0
29NK	80-100	0.05-0.2	0.1-1.0	—	1	2
D16T	700-800	0.20-0.4	1.0-2.5	—	1	2
Steel 45	80-200	0.20-0.6	1.5-6.0	—	1	1.1- 1.3

Use of 1 T of articles made from nontungsten alloys of type KTS secures a savings of as much as 2 T tungsten per year.

Silinite-R is a highly dense material based on silicon nitride, intended for fabrication of blade type cutting tools to be used in semifinish and finish turning of crude and quenched steels, pig irons, alloys, nonferrous metals and polymer materials. Its composition does not contain scarce tungsten or compounds thereof. It has excellent stability of physical properties at high temperatures.

Cutters tipped with silinite-R when used to machine crude steels and pig irons are the equal of cutters with hard alloys T18K6, VK3, T30KN, T15K6. When machining quenched steel (50 HRC or higher), they are 5-10 times superior in durability to cutters made of hard alloy T15K6.

As compared to the best Western and Soviet tool ceramics, silinite-R is tougher and more stable when working under conditions of intermittent cutting (milling) of pig iron, crude and quenched steel.

Fabrication of one million cutting tips of silinite-R saves around 10 T tungsten.

Hexanite-R is a superhard semicrystalline material based on the wurtzite modification of boron nitride. The creation of hexanite-R first made possible the solving of the problem of stable functioning of a bladed tool when working very hard materials in conditions of both intermittent and continuous cutting on NC lathes, automatic lines, and machining center type lathes (Table 2).

Table 2. Technological Characteristics of Hexanite-R Tipped Cutters

Material machined	Cutting regime			Average toughness of cutter, min	Roughness R_a, µm
	v, m/min	S, mm/rev	t, mm		
Steel KhVG (62-64 HRC)	50-150	0.02-0.1	0.10-0.5	90-60	1.25-0.63
Pig iron SCh 21 (180-210 HB)	300-800	0.02-0.2	0.10-0.1	100-60	2.50-1.25
Steel 30KhGSNA	75-300	0.02-0.1	0.10-0.5	100-60	0.63
Alloys VK10 - VK25 (84-88 HRA)	35-30	0.02-0.1	0.05-0.5	40-15	0.63-0.32
Wear-resistant facings (70-80 HRA)	30-80	0.02-0.1	0.05-1.0	60-30	0.63-0.32

Note: Iron SCh 21 machined with lubricating fluid, other materials without

The use of a bladed tool tipped with hexanite-R can in some cases replace the low-productive process of grinding with lathe machining, increasing the labor productivity by a factor of 2-10. It can handle interrupted surfaces of hardened parts (key slots, intricate cutouts, gear teeth, etc.), increasing the toughness of the cutters by a factor of 10-20 as compared to hard alloy cutters in the machining of quenched steels, increasing the machining speed for quenched steels and pig irons by a factor of 3-5, and ensuring a precision of workmanship on the level of quality 6-7 and a roughness of the machined surface R_a=1.25-0.08 µm.

Abrasive paste KT is a composition of titanium carbide powders, sorted according to grain size and bound together by a surfactant. The bonds and surfactants used are natural and synthetic fatty acids and their derivates (soaps, waxes, alcohols), as well as various hydrocarbons, glycols and their derivates, polymers, etc.

The composition of the paste and the ratio of components depend on the specific conditions of the application (Table 3).

Table 3. Technological Characteristics of Abrasive Pastes Based on Titanium Carbide

Machining	Grain size of paste, µm	Paste outlay, g/cm^2	Surface roughness R_a, µm	
			before machining	after machining
rough finishing	630/500 - 50/40	0.30-0.5	1.500	0.320
semi-rough finishing	60/0 - 14/10	0.07-0.3	0.200	0.100
fine finishing	14/10 - 3/2	0.05-0.2	0.063	0.032
polishing	3/2 - 1/0	0.03-0.1	0.025	0.020

Use of the KT pastes instead of diamond abrasive pastes and powders in the machining on nonferrous metals enables a 1.5-2 fold increase in the labor productivity, reduced roughness of the machined surface, a 1.5 fold increase in durability of the parts, and a reduced degree of charging of the machined surface with abrasive.

In the machining of ferrous metals the KT pastes are the equal of diamond and Elbor pastes in terms of productivity (removal of material). Their use is most effective in honing and polishing of parts.

When machining parts in a magnetic field, powder having magnetic and abrasive properties is used as the cutting agent. Such "elastic" tool makes it possible to resolve many problems of the metalworking industry: mechanization of labor-intensive polishing and honing jobs, machining of parts of intricate configuration, such as turbine blades, crank shafts, and so on.

The most suitable for mass use in industry are cast magnetic-abrasive powders obtained by dispersal of melts. In this case, the excellent usage features of powders are combined with low prime cost.

One of the promising areas of use of the new magnetic-abrasive powders (Polimam type) is the tool industry.

UDC 621.7.044:678.06

Power Tools for Machining of Polymer Composites

907F0225B Kiev TEKHNOLOGIYA I ORGANIZATSIYA PROIZVODSTVA: NAUCHNO-PROIZVODSTVENNYY SBORNIK in Russian No 1, Jan-Mar 90 pp 23-24

[Article by V. Ye. Shvetsov, B. V. Lupkin, and V. B. Yelenevich]

[Text] In the modern machine industry, parts made of high-strength polymer composites (PC) have become widespread. These have a tensile strength limit of more than 750-800 MPa and are reinforced with glass, polymer, boron, and carbon fibers.

At the machine building enterprises, the labor-intensive jobs of machining of PC generally have a low level of automation. Portable pneumatic machines are mostly employed, furnished with bladed or abrasive tools of inadequate toughness and productivity.

In order to increase the level of mechanization and reduce the labor- intensity of the machining of PC parts, power tools were designed and built in an experimental operation at the Ukrainian branch of the NIAT, including some with pneumatic or electric drive (see table).

Characteristics of Mechanization

Name, model	Area of application	Technical data	Effectiveness
Pneumatic disk shears NDP-1.5, NDP-3A, NDP-4A	Trimming of the process allowance of 1.5-4 mm thickness. Cutout of carbon, glass, and organic plastics and prepregs	Frequency of rotation of spindle respectively 30, 3500, and 6 rpm; drive power 150, 150, and 400 W; weight 1.4, 0.8, 5.5 kg	Labor intensity of machining reduced by factor of 1.5-2. Economic impact 2.5-3 thousand rubles per item
Lever shears with pneumatic and electric drive NRE-1, NRP-23	Cutout of carbon, glass, and organic plastics, trimming of process allowance up to 1.5 mm thick, cutting of sheet material and prepregs	Interchangeable adapters for pneumatic and electric drills EI-10367 and SM-11-6-3600. Weight 1.8 and 1.3 kg, respectively	Same

Characteristics of Mechanization (Continued)

Name, model	Area of application	Technical data	Effectiveness
Pneumatic scarfing machines MZP-1, MZP-2A	Scarfing of surfaces of single and double curvature of outer and inner contours, removal of facets, blunting of sharp edges in parts made of carbon, glass, and organic plastics and in glass honeycombs	Spindle turning speed 18,000-20,000 rpm; motor power 220-400 W; weight 1.2-1.5 kg. Individual dust suction	Same
Lever shears (right and left handed) NRR-1, NRR-2	Cutting of sheet materials up to 2 mm thick along straight and curved contours	Blades strengthened with hard alloy. Weight 0.3 kg	Labor intensity of machining reduced by factor of 1.5. Economic impact 1,200 rubles per item
Pneumatic trimming machine MOP-1A	Fine trimming of process allowance up to 5 mm thick	Spindle turning speed 17,000 rpm	Labor intensity of machining reduced by factor of 2. Economic impact 2,500 rubles per item
Pneumatic hacksaw NP-22	Trimming of process allowance in profiled windows of SVM	Length of travel of saw blade (made of steel R18) 22 mm. Number of dual passes 2100. Weight 1.5 kg	Same

The results of testing the power tools in production conditions testify to the effectiveness of their use: the requisite precision of workmanship of the PC is ensured with no spalling, peeling, or tattering of the surface edges of the parts. There are plans to create a mechanized tool with independent power source. Further improvement in the power tools requires an expanded assortment of strengthened bladed and high-efficiency abrasive-diamond tools for cutout of PC and scarfing of honeycomb structures. Expansion of the field of investigation in the area of experimental determination of economically warranted cutting regimes for PC according to the kinds of machining will make it possible to design typical technological processes of machining of composites in the computer.

Adoption of the above-described tools for machining of PC has made it possible to increase the level of mechanization of manual jobs up to 80%, reduce the labor intensity of the machining by a factor of 1.5-2, shorten the cycle of production engineering, and substantially improve the work culture and safety.

UDC 621.291

Ensured Precision of Positioning of Industrial Robots

907F0225C Kiev TEKHNOLOGIYA I ORGANIZATSIYA PROIZVODSTVA: NAUCHNO-PROIZVODSTVENNYY SBORNIK in Russian No 1, Jan-Mar 90 pp 38-39

[Article by L. P. Bondar]

[Text] The presentday gripping elements of industrial robots (IR) have their deficiencies: it is difficult to ensure total orientation of the jaws when grasping an object; the holding of the object during transport and assembly of a product is not reliable; considerable time is spent on adjustment during retooling.

An expanded volume of assembly work and the increased demands on the quality of such work are connected with the need to solve the problem of ensuring the stability of position of an oriented part in the grasping element of an IR.

The possibilities of manipulating an object are considerably augmented by replacing the clamping type two-finger grab with a three-finger type. In order to grasp an object of any given shape and weight it is necessary to determine the area of disposition of the three rational points of contact on its surface.

Theoretically, the number of rational points of contact is determined by means of a triangle constructed around the conditional center of gravity. The vertices of the triangle are located in the places where the rational points are situated on the surface of the object. The plane of the triangle passes either along the axis of symmetry or perpendicular to it, depending on the relationship between the outside dimensions of the solids of revolution.

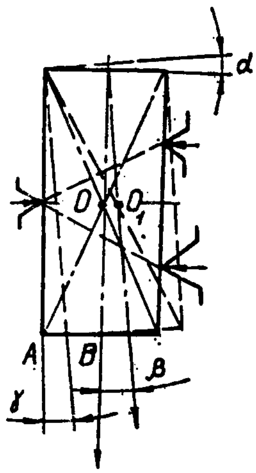
When grasping an object with three vises, the position of its axis changes with respect to the axis of the grab, and therefore skew angles of different magnitude are formed. Thus, skew angle γ is formed by the forces of squeezing of the vises of the grab on the surface of the object and is determined by the line of contour of the plane of the grab in the starting A and final B positions of the object in the grabbing element (see figure).

The skew angle α is formed by the position of the plane of the grab with respect to the orienting surface in the starting A and finishing B positions of the object.

Skew angle β is formed as a result of shifting of the center of gravity of the object in the grab. It is determined by the axis of symmetry passing through the center of gravity O in the starting A and the center of gravity O_1 in the finishing B position of the object.

The shifting of the axis of the object in the grab of the IR will be reduced with proper choice of the region of the rational points on the contacting surface of any given outside dimensions.

The action of the forces of inertia in the process of the grabbing is negligible, and therefore need not be factored



Arrangement of Rational Points of Contact (Surface of Grab at End Face of Object)

in. Different combinations of grabbing and orienting surfaces are possible, for example:

1) the surface of the grab is located at the end face of the object, the orienting surface is on its cylindrical portion;

2) the surface of the grab is on the cylindrical portion, the orienting surface at the end face;

3) the surface of the grab and the orienting surface are on the cylindrical portion.

In the first and second case, the secant plane passes along the axis of symmetry drawn through the conditional center of gravity, in the third case it is perpendicular to the axis of symmetry (also drawn through the conditional center of gravity of the object). The inscribed triangle is constructed, its vertices being located on the surface of the secant plane, and the disposition of the rational points of contact on the surface of the grab is determined. In the starting position, the vises of the IR grab must be placed opposite the vertices of the triangle at a distance of 5-10 mm.

Experimental investigations of models of universal grabs have shown that the labor productivity is improved by a factor of 1.65 and the adjustment time of the IR is reduced by 50% with centralized preparation of the operation of grabbing of an object.

UDC 621.73.001

Concept of Development of Forge-Press Machine Building in USSR

907F0171A Moscow KUZNECHNO-SHTAMPOVOCHNOYE PROIZVODSTVO in Russian No 9, Sep 89 pp 2-3

[Article by A. I. Petrov and I. M. Podrabinnik]

[Text] The following are distinguished for working out the concept of forge-press machine building in the USSR among the large number of factors that determine the production and technical level of forge-press machine building:

production of forge-press equipment;

the technical level of KPO;

specialization and the technical level of KPO production;

maintenance and repair of KPO.

State of Problem

Production of Forge-Press Equipment

High efficiency predetermined the considerable rates of growth of KPO production in the USSR.

The specific proportion of KPO (by quantity) in the total output of metalworking equipment (MOO) has increased sequentially in the USSR. In 1965, the specific proportion of KPO in the total output of MOO in natural expression comprised 15-7 percent, it was 22.5 percent in 1985, and it was 23.9 percent in 1986. This occurs primarily due to a reduction of the number of machine tools manufactured. Nevertheless, the specific proportion of KPO in the total output of metalworking equipment in cost expression decreased during the 11th and 12th Five-Year Plans and comprised 22.6 percent in 1980, 20.2 percent in 1985, 19.1 percent in 1986, and 18.7 percent in 1987.

The increase of KPO production at enterprises of Minstankoprom [USSR Ministry of Machine Tool Building and Tool Industry] has outstripped the total growth of KPO in the USSR since 1965. The output of KPO in the USSR has increased 1.5-fold in quantity and 4.3-fold in volume from 1965 through 1985. The output of KPO at enterprises of Minstankoprom increased 1.7-fold during this period in quantity and 4.7-fold in volume.

The specific proportion of KPO manufactured by enterprises of Minstankoprom increased from 65.8 percent in 1965 to 74.2 percent in 1985 in total production throughout the USSR in natural expression and from 82.5 to 90 percent in cost expression.

The most important feature of developing forge-press machine building during this period was improving the structure of Minstankoprom production equipment by increasing the output of the most progressive categories of KPO: automated (from 12.4 percent in 1965 to 28.1 percent in 1985) and heavy and unique machines (from 3.4 percent in 1965 to 5.2 percent in 1985).

KPO is now being produced in the USSR for technical retooling: separation operations, sheet stamping, bending, straightening and shaping, cold and hot volumetric stamping, rolling and forging, reworking plastics and other nonmetal materials, formation of products from powder materials, reprocessing scrap metal, assembly operations and a number of other processes.

The enterprises of the subsector annually produce 550-600 models of equipment and approximately 130 types of universal and specialized KPO has been developed.

The needs for such types of equipment as one- and two-crank simple open presses, screw arc-stator presses, pneumatic forging hammers, and three-roller sheet-bending machines are being satisfied.

The needs for progressive molding equipment such as four-crank simple closed presses, one-, two-, and four-crank double presses, hydraulic ram presses, and automatic forge-press machines are not being satisfied. The output of equipment for powder metallurgy, nonmetal materials and scrap processing equipment is inadequate.

Many types of progressive forge-press equipment are not manufactured in the USSR: shears with mutually perpendicular blades for cutting rolled sheets, hydraulic sheet-stamping double frame presses, equipment for rotational stretching, complexes for patternless layout stamping of parts from sheets, pipe-bending and spring-winding NP machines, cold-stamping automatic position machines for rod-type and nut-type products of increased precision and strength, presses for spherical stamping, horizontal forging machines with horizontal disconnect of dies and other equipment.

The disadvantage of the structure of the manufactured equipment is the primary production of medium-sized machines; small machines and various types of large-force machines are not being manufactured.

The characteristic feature of the leading machine-building sectors is the use of one-piece and pressed large parts in designs of manufactured equipment instead of welded or assembled units and housing components.

An increase of the unit capacity of modern power plants and machines, expansion of the construction of electric power plants, development of new types of airplanes and helicopters, and further development of automotive construction, tractor, heavy and transport machine building and other sectors of industry dictate the need to produce large forgings and stamped blanks of complex design from carbon and difficultly deformable steels and alloys.

A great disadvantage is the absence of modifications of basic models, distinguished by the dimensions of tables, by the stroke of the slide, by the frequency of strokes, by the number of positions and by other parameters that take into account the requirements of users. These modifications must be developed on the basis of sheet shears, two- and four-crank presses, sheet-bending presses, roller and sheet-stamping machines, multiposition automatic sheet-stamping machines and so on. The nomenclature of manufactured MP KPO and GPS [flexible manufacturing system] is limited.

The characteristic feature of manufactured equipment is the primary use of a mechanical drive instead of a more efficient hydraulic drive. A hydraulic drive is little used on sheet shears, sheet-bending presses, sheet-bending rolling machines and other types of equipment.

The enterprises of Minstankoprom develop and manufacture automatic and semiautomatic lines for separation of initial materials, sheet stamping, bending and straightening, cold and hot volumetric stamping, but the need for automatic lines is not being satisfied.

The production of forge-press equipment in the United State and West Germany exceeds the output in the USSR.

Quantitative comparison of the production of various types of traditional equipment indicates that more less efficient equipment and less more efficient equipment is being manufactured in the USSR than in the United States.

Compared to the United States, the following are manufactured in the USSR: tenfold more open presses, fourfold more sheet shears, and fivefold more one-rack hydraulic presses. The following are not being manufactured: fast-stroke progressive automatic presses, output of simple and double-action hydraulic frame sheet-stamping presses and so on.

Technical Level of KPO

The technical level of manufactured equipment as a whole corresponds to the modern level. It should be emphasized that the needs for KPO are not yet being adequately satisfied and many types of machines are not being manufactured.

Problems of increasing the performance of manufactured equipment, of reducing its metal and energy consumption, of equipping it with mechanization and automation devices, increasing the reliability and precision, and increasing the specific proportion of equipment with electronic, including microprocessor control devices, remain timely.

The manufactured KPO must be fully outfitted with stamping equipment, heating devices, and monitoring and measuring and diagnostic devices.

Specialization and Technical Level of KPO Production

The plants and PO [production association] of the subsector of Minstankoprom and enterprises of a number of ministries and departments manufacture forge-press equipment in the USSR.

The enterprises of the subsector can be divided into three groups with regard to the nomenclature load and specialization. The first group comprises narrowly specialized enterprises, which manufacture one or two types of KPO, which limits their capabilities in development of equipment production of new nomenclature.

The second group includes plants that manufacture four-eight types of equipment. Enterprises of the third group are multinomenclature and manufacture more than 10 types of equipment, up to 60 models annually, including a large number of special machines. More progressive scarce equipment is manufactured at such enterprises as the

Voronezh PO for output of TMP and KPO, the Azov PO Donpressmash, the Orenburg PO Gidropress, and the Dnepropetrovsk PO for output of TP.

All plants based on KPO of main specialization manufacture automated complexes, machining centers, GPM [flexible manufacturing module], and lines.

The plants of the subsector manufacture a large number of KPO models for machining nonmetal materials:

briquetting of peat, Dinas brake products, piles, and salts;

pressing loose materials, asbestos products, and refractory sprockets;

packaging wood shavings, waste paper, cotton and so on.

Enterprises of the different ministries and departments produce KPO. The plants of Minavtoselkhozmash, for example, manufacture a large number of universal presses and complexes, besides special equipment—these are one-crank open presses with force of 1,000 and 2,000 kN and complexes based on them, stamping presses and presses for cold extrusion and so on.

Analysis of data on the number of KPO enterprises and of the number of workers in them in the United States indicates that enterprises at which less than 20 and from 20 to 500 persons work predominate.

Higher labor productivity is present at enterprises at forge-press machine building in the United States with high level of cooperative production.

The technical level of enterprises of forge-press machine building of the USSR is characterized by obsolete casting equipment, by a large amount of obsolete and physically worn forge-press and heating equipment, by an unfavorable age structure of casting, forge-press and metalworking equipment, by a low level of specialization of cast, welding and forge-stamping production, by a shortage of assembly areas at the leading plants of the sector (Voronezh PO in manufacture of TMP and KPO, the Ryzan Plant TKPO), and by insufficient capacity of experimental plants, shops and experimental bases.

Centralized production of standardized assemblies in the subsector is limited.

Maintenance and Repair of KPO

The KPO manufacturing plants essentially do not support users with spare parts and the necessary repair documentation. The inadequate results of operation of equipment manufacturing plants to increase reliability, including repairability, also causes complaints of users.

The PO Tekhrempressmash (Khmelnitskiy), which has its own repair base and is involved in centralized repair and maintenance of automatic thermosetting machines and NP equipment, has been organized in the subsector of the forge-press machine building.

A production engineering enterprise has been developed within the Dnepropetrovsk PO for manufacture of TP for repair and maintenance of equipment manufactured by the association. Groups on completion of starting and adjustment work have been organized at the Voronezh PO for manufacture of KPO, at the Ivano-Frankovsk PO Karpatpressmash and other plants.

On the whole, centralized efforts to repair and maintain KPO comprise less than 5 percent of the need; the need for major overhaul and modernization of equipment is being satisfied by less than 2 percent and the need for spare parts is being satisfied by 10-12 percent.

Maintenance and repair of forge-press equipment are performed by enterprises that operate the KPO.

The average cost of one major overhaul at enterprises of machine-building ministries comprises more than one-third of the budget cost of the machine. The actual idle times of the KPO during repair is 1.5-3-fold greater than the planned norms.

The repair bases in the machine-building sectors are considerably weaker and the technological level of repair of KPO is also low. The expenditures on repair during the total service life of the equipment exceed two-threefold the budget cost. The quality of repair is frequently unsatisfactory and the consumption of spare parts is usually higher than technically substantiated standards.

The foreign manufacturing company develops well-organized branch maintenance networks for the manufactured equipment—repair bases, spare parts warehouses, and consultation stations—throughout its territory and abroad.

Concept of Development

The concept of development of forge-press machine building proposes:

that the volumes be increased and the structure of production of forge-press equipment be improved;

that the progressive equipment of the new nomenclature be developed and that the KPO production in the USSR and CEMA countries subsequently be integrated to completely satisfy the need of the national economy and to restrict imports from capitalist countries to a minimum or to increase export to volumes comparable to import;

to increase the technical level and reliability of forge-press equipment and delivery products for the purpose of using it efficiently in the national economy and of guaranteeing competitiveness on the foreign market;

to develop capacities, to improve specialization and to increase the technical level of production of forge-press equipment;

to develop a centralized repair (with supply of spare parts) and maintenance system of KPO in the USSR and abroad.

Preliminary proposals have been worked out to implement the concept.

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