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PHYSICAL SCIENCES AND TECHNOLOGY
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SOCIO-PHILOSOPHICAL PROBLEMS OF MAN-MACHINE SYSTEMS: ARTIFICIAL INTELLIGENCE AS A COMPLEX SCIENTIFIC AND TECHNICAL PROBLEM

Moscow VOPROSY FILOSOFII in Russian No 4, 1979 pp 76-78

[Article by E. V. Popov: "Systems of interaction of man and computer in natural language"]

[Text] The concept of "artificial intelligence" was introduced by specialists in computer technology and programming. It usually implies an engineering discipline intended for the development of computers of programs capable of action which would be called intellectual if it were done by humans (1). This definition focuses attention only on the inclination of artificial intelligence (AI) to solve non-numerical problems of a particular type on the computer which, until recently, were included in the sphere of human activities. It is not claimed that programs or devices which solve these problems possess intelligence in the human sense. The relevancy of the very term "artificial intelligence", of course, could be criticized, but this would hardly be profitable since the term is so popular.

Most specialists (including the author) relate artificial intelligence to technical disciplines (2) and feel that the search for a theory of artificial intelligence makes no more sense than a search for, let us say, a theory of civil engineering. Instead of a unified general theory of artificial intelligence, there is a series of theoretical disciplines which are employed in AI. Among these are linguistics, psychology, mathematic logic, theory of computations, theory of algorithms, theory of information structures, theory of graphs, theory of heuristic investigation, etc. The basic applied functions of AI include automatic problem-solving, "comprehension" and synthesis of texts, translation from one language to another, proof of theorems, recognition of visual models and speech, representation and storage of knowledge, development of robots, and so forth.

Many of the difficulties with AI are reflected in the problem of developing a system of interaction of man with computer in natural language (NL). This allowed several experts to consider their problems identical. The process of interaction in natural language includes the following problems: "comprehension" and synthesis of texts, automatic decision retrieval, recognition and synthesis of speech, representation and storage of knowledge.

No sector of the national economy exists where computer technology is not used. But day-to-day and mass utilization is hindered by the fact that interaction with computer may now be done only by programmers, the demand for which is constantly growing. Consequently, it is becoming evident that the need for problem-solving of human interaction with computer is not only due to the quantitative increase in programmers, but also on the plane of interaction with computer in natural language, which has several advantages over formalized programming languages. First of all, because of the practical lack of a training stage, it is possible to conduct preliminary training. Secondly, there is a rise in efficiency and convenience of human interaction with computer. Finally, the number of errors permitted by man in such interaction drops sharply.

The development of systems realizing interaction of man using natural language with the computer should, we feel, be based on principles of universality, development and interdisciplinary penetration. Universality implies: a) universality of choice of method of representation of knowledge (data bank) which will permit expansion (during evolution of a system) of the class of phenomena representable in it without change in processing method; b) universality of algorithms and programs (software) to reveal the possibility of expanding functions of the system not through remodelling, but through adjustment of software; c) independence of software and data banks to permit expansion and modification of models of the environment without changing programming equipment.

The principle of development anticipates fulfillment of systems with natural language in several stages due to the current impossibility of solving the problem in its total scale. As such, these systems should be built on a modular principle, according to which it is possible to alter both the sequence of request of individual modules of the system, their number and their function without changing the entire system. As a matter of fact, this means the development of complicated versions of a system (retaining its continuity) by successive lifting of constraints imposed on the interaction process. The process of selection of these constraints is now coupled with problems, on one hand, of specifying constraints acceptable to system users and the determination of their consequences (in other words, there is no guarantee that interaction will be at all possible with a chosen constraint); and, on the other hand, with problems of determining (prior to system design) the adequacy of the media used in its design to solve the problem of interaction in a selected subset of natural languages. In practice, attempts are not even made to solve this problem, and the first constraints encountered are accepted. Thus, for example, the author knows of several teams (working without linguists) who have attempted to create natural language systems based only on semantics, neglecting morphology and syntax of Russian. The failure of these attempts, apparent to linguists, is unclear to programmers.

The principle of interdisciplinary penetration anticipates the need for solving the problem of interaction of close and constant contact of specialists of various fields, primarily linguistics and programmers. It seems inadmissible to us that there is the trend of specifying the limits to which linguists are involved in the program and then programmers in the process of solving the problem of interaction. Unfortunately, this trend has found almost universal private acceptance.

I would also like to touch briefly on a description of the status and outlook for development of the POET system (program of processing economic texts). The particular choice of this system is not accidental. The author is unaware of any other currently operating system which could be related, with complete justification, to natural language systems; this does not, of course, mean that the POET system solves all problems of interaction, but it has been worked out in strict correspondence with the above principles, permitting it to evolve while continually increasing its possibilities. The POET system was developed by a team led by the author with the aid of co-workers of the department of structural and applied linguistics of Moscow State University, chaired by Prof. V. A. Zvegintsev.

In the first stage of the process of interaction, the following constraints were introduced: language of interaction is commercial economic Russian process; interaction is carried out by individual non-connected, simple interrogative sentences--free of inversions, ellipses or anaphorisms; internal representation allows only the static (not dynamic) world without connections between events (dynamic, that is, a change of data base, is done without consent of the POET system); the data base has a rigidly fixed format restricting topics of interaction; the system can not, in the event of misunderstanding of an interrogation, direct the user to periphrase it.

The system response time to a 15-word interrogation is 30 seconds in the third-generation model YeS-1050 computer.

In the second stage, to be completed in 1979, the process of interaction will be characterized by the following features: interaction is carried on in dialogue mode consisting of several interrelated sentences containing inversions, subordinate sentences, elliptical and anaphoristic phrases; in the event of misunderstanding of an interrogation (due to user error, ambiguity of interrogation or system constraints), the systems reports to the user on the causes of failure in concept-terms and directs the user (using questions or statements) to change the initial interrogation; internal representation permits the expression of casual relationships between events.

The process of designing systems with natural languages is now, we feel, retaining the following difficulties: the small number and discreteness of groups engaged in its development; underestimation of the problems of interdisciplinary cooperation. Many linguists feel that problems are theirs alone, while programmers feel that they can get along without linguists in general; both forget about psychologists, philosphers and members of certain other specializations, without which the solution to the problem of interaction, in its full scale, is impossible; and finally, the lack of basic research in the field of representation of knowledge, understanding of semantics and structures of a connected text.

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CYBERNETICS, COMPUTERS AND AUTOMATION TECHNOLOGY

VIRTUAL OPERATION SYSTEM FOR SMALL AND MEDIUM COMPUTERS

Moscow PROGRAMMIROVANIYE in Russian No 6, Nov/Dec 78 pp 50-59 manuscript received 23 Feb 77

[Article by Sokol, Ya. and Navratil, V.]

[Text] This article examines plans for a virtual operation system designed for small and medium general purpose computers. Let us first touch upon the basic requirements imposed on an operational system.

Each operational system (OS) should support the efficient use of machine resources under various operating conditions: in batch processing, remote data processing and in limited operation during time-sharing.

The system should guarantee reliability in the event of hardware malfunctions or programming errors. This requirement is important, especially in data bank applications.

Considering the labor-intensiveness of systems design, long service life must be supported. It is desirable to anticipate the system's design and evolution.

It is also very important to provide simple use and maintenance of the system, often the deciding factor for technical workers and users (programmers and operators); this has a substantive effect on system acceptance by the user. If the system can be kept rather simple and logically consistent, the number of documents required by the user will drop substantially.

Special attention should be given to compatibility of data and programs between devices with different hardware (memory capacity, different peripheral devices, etc.), between separate versions and modifications of a proposed system which will undoubtedly appear during its service life and which should not cause changes in the user's programs. One condition for attaining this compatibility is to secure a system interface which would be accurately defined and guaranteed for the future at the data and program level in initial symbolic form. The interface should anticipate independence of programs from types of I/O devices and provide retained efficiency in the event of further expansion of system functions.

The proposed system ensures complete transferability of sequential data files from the most common third-generation operating systems and contains programs for converting index-sequenced data files. Programs written in universal programming languages can be transfered in symbolic form without change even if they were first intended for I/O devices of other form. Programs written in Assembler must be translated. If they are independent of the form of translation, marking and length of system array, control units and macroinstruction execution blocks, they can be transfered unchanged from unified system disk-operating systems. Carry-over of translated programs can only be done in exceptional cases: if no references to the operational system are contained.

An important aspect of the project is the labor-intensiveness of realization, testing, putting into operation and maintenance of the system within its entire service life. Much attention is also given to the problem of incorporating new I/O devices into the system. This important practical question has not been satisfactorily resolved in all current systems, this involving great losses.

The general concept of proposed system is based on the sequential use of principle of the virtual nature of memory not only for the user, but for the system per se, in centralization of all significant functions of the system and in dynamic distribution of resources.

Terminology and concepts of operational systems of the Unified System of Computers are widely used in this article.

2. Systems Resources

The basic task of the operating system nucleus is to control the use of systems resources. Systems resources in this system are the following devices and hardware: central processing unit and main storage, virtual address space, storage region and mag disk working memory, I/O devices, program library, data files, and op system programs.

Storage regions and working disk memory are specified dynamically as needed in units of 64 Kbytes. The entire volume of working memory on mag disk is combined for all applications and for all users in a single systems retrieval file which can be placed on several mag disks. The system specifies segments of working memory only if needed. This achieves substantial savings of disk memory and one shortcoming of the current system is eliminated that has often hindered the use of multiprogramming, especially in the small computer.

Place in the storage region for created (output) files is reserved and is specified at the moment a file is opened. In the case of changing files, the earlier file is specified for the availability of one user. As a result, the danger of deadlocks could appear, but it is rather theoretical in the given case.

It is completely different with other devices which are specified only for one user. All I/O devices, except floppy disks and operator consoles, are task-specified for exclusive use for all execution time. In some cases (for example, an alphanumeric printer), the above strategy often involves a reduction in productivity of the entire system, since a computer provided with a single alphanumeric printer can execute only one task, though neither the central processing unit nor the alphanumeric printer is overburdened. The proposed system anticipates work with virtual peripheral devices using the principle of balanced rate of data transmission by means of floppy disk (SPOOL). Virtual I/O devices, whose number is not limited, may be simultaneously shared by any number of users. The operating principle of virtual peripheral devices will be described below.

Sharing of the central processing unit (CPU) by several independent user tasks and several subtasks of a single assignment or system is a regular phenomenon and will be described below (see Section 5, §1).

3. Control of Main Memory

Sharing of main memory by several parallel executed tasks is done in the proposed system by the mechanism of virtual addressing supported by computer devices.

Virtual address space implies an abstract concept in this system, denoting a set of numbers by means of which program objects can be identified (instructions, data). Each parallel executed task has its own address space which can be dynamically raised almost to total capacity of 16 Mbytes. In practice this means that in devices, translation of virtual adresses is controlled for each parallel executed task using its own segmented array; replacement of segmented arrays in transition from one task to another is done by altering the contents of the system register of the segmented array.

Program objects denoted by virtual addresses may be maintained: constantly in the phase library (intrinsic programs), temporarily in disk storage region (changing portions of programs and working memory).

The form of virtual address space reproduced by portions of the library or disk storage region is optionally continuous. In the general case, one part of the virtual address space can be arranged in the library, while another part--in disk storage region. An important consequence of this concentration is that the shape of virtual address space can be reproduced dynamically. This means that parts of virtual space are appropriated by the disk memory region only at the instant of appropriation of the corresponding virtual address to objects which can be altered during the computation. Virtual space appropriated for objects of continuously changing nature (e.g., multiple input programs) is placed only in the phase library, while space whose address at a given moment is not occupied by any object remains unpositioned.

Objects are transfered from the library or disk storage region, if necessary, into real memory, generally using an ordinary page-by-page mechanism, except for the resident portion of the supervisor which is carried into real memory at the start of system operation (using the IPL program) and several special cases of phase entry.

1. Virtual Address Space (VAS)

VAS of each user task consists of two basic parts: shared virtual space (SVS) and private virtual space (PVS).

SVS is space common to all user tasks; corresponding positions of segmented arrays of all executed tasks indicate identical page arrays. SVS is found in the lower portion of each virtual space, starting with the zero (virtual) address. The upper limit of SVS is determined with system generation. Since SVS does not contain any objects which would have to be temporarily entered during computation into the disk storage region, its shape will always appear only in phase library. SVS consists of the following parts:

Space of Identical Addresses (SIA)

This contains the nucleus of the control program and corresponding systems arrays. SIA constantly appropriates identical real addresses and its shape appears in real memory as a result of execution of the IPL program. Real memory, carried to objects stored in SIA is not subjected to page-by--page distribution of memory; thus it is not necessary to reproduce the shape of SIA in the disk storage region. The actual volume of SIA can be selected in generation of the system. If the selected voluem of SIA is greater than that required by resident portions of the supervisor, other unoccupied portions can be used for program operation in real memory mode. Maximum SIA volume is, in this case, defined by the capacity of main memory used by the computer.

Separate Virtual Program Space (SVPS)

Here are kept the remaining parts of the supervisor, LIOCS modules, task input control program, etc. The shape of this portion of virtual space is again only in the phase library. Separage pages are transfered into working memory directly from the phase library. Since all programs intended for SVPS are multiple input, they can not be rewritten in disk storage.

Separate Virtual Working Space (SVWS)

This is specified dynamically according to parts of the program executed in SVPS for storage of temporary working data. Objects stored in SVWS exist only in reserved working memory which, during use, is excluded from page--by-page distribution (blocked). After replacement of blocking of reserved working memory, objects are considered destroyed. There is no need to reproduce the shape in disk memory for SVWS. Data of a long-term nature are retained using SVPS programs in regions reserved in SVS.

Private virtual space of all user tasks starts with the virtual address defined by the upper limit of VAS. It is an address to which are tuned all user programs, translators and other systems programs. From this limit, virtual spaces of different users are separated, i.e., segmented arrays of individual SVS indicate various page arrays. Described organization permits in all simultaneously executed user tasks the use of programs written in identical addresses. It is thus not necessary to pre-determine in which user spaces to start up a specific program and when the program is entered into memory, site-by-site alignment is not necessary.

At the start of solution of a task, the users have available a part of SVS (i.e., written corresponding page arrays or reserved space of disk storage) according to requirements defined in task input control instructions. The volume of SVS can be dynamically expanded during computation to a maximum of 16 Mbyte for each user. Arrangement of all SVS is primarily done in the phase library. After program entry into working memory, the shape of unchanged pages remains in the phase library, whereas altered pages of the program and data are placed into the disk storage region as required. Organization of segmented arrays and page arrays permits two or more SVS to be combined in this system. In such cases, the steps of tasks being executed in these spaces use identical programs. A condition for separation of SVS is the multiple input nature of programs and their entry into all SVS in identical addresses.

2. Phase Library and Disk Storage Space

The phase library reproduces the long-term shape of separate and all private virtual spaces; in the disk storage region is reproduced the temporary shape of these parts of private virtual spaces which were changed during computation and can not (or should not) be in working memory at the time.

The basic image unit of VAS in the library or disk storage space is the segment. The SVS shape in the phase library is always continuous in terms of segments (i.e. programs are edited in SVS by segments), just like the shape of SVS in disk storage space. In observing agreements for forming user program phases described in section 5 §1, the shape of SVS in the phase library is also continuous in terms of segments, permitting the concentration of all carries between the phase library and working memory exclusively with the page-by-page mechanism and eliminating the ordinary function of phase entry.

Physical segments in phase library are specified during editing and are carried to the virtual spaces. Segments in the disk storage region are carried to SVS segments at the instant of demand for specification of a part of SVS, i.e. at the start of execution of a task or in sequence, with dynamic expansion of SVS during execution.

3. Real Memory (RM)

Real memory consists of two parts. The first part, starting with the zero real address, corresponds to part of SIA which is constantly occupied by the resident portion of the system. The second part (unoccupied) forms the entity of physical pages which are carried to pages of separate and private virtual spaces as needed. The subprogram of the control program which realizes page-by-page mechanisms does periodic monitoring of optional presence in working memory of pages, releases the appropriate physical pages for further utilization and transmits altered pages to the reserved portion of disk storage.

4. Direct Input-Output System

The greatest hindrance of the multiprogramming mode is the constraint on the number of peripheral devices, primarily printers and readers for punch card equipment. Thus the proposed system includes media for operation with virtual peripheral devices, the number of which is not constrained and which can handle several tasks. Virtual devices operated by the following principle. For each virtual device and for each user, the system forms a special working file in disk memory in common storage. Each I/O demand in the virtual device is executed in a special systems subprogram which performs data exchange. In the event of peripheral input devices, the data block is read from the disk and the appropriate amount of data blocks is transmitted to the user region. For an output device, user data is transfered to the systems buffer or, if it is filled, data are entered into the working space on the disk. Carry from disk to disk occurs with the aid of the page-by-page mechanism. The actual physical carry of data from the input device to the disk (or from disk to the output device) is done by an independent systems subtask totally asynchronously, but in such a way that data carry of one task (task group) takes place jointly. Thus, simultaneous direction of the results of two tasks toward virtual printers is ensured, although in physical form, both results are sequentially printed by one printer. Even one task can operate with several virtual printers.

Virtual devices can be used for readers (punchcard and punched tape perforators), for printers, diskettes and remote data processing devices. Indirect I/O systems programs simultaneously eliminate distinctions of individual peripheral devices, so that all virtual input devices, from a program point of view, operate as a reader from punched cards and virtual output devices operate as a perforator of punched cards or printing device. Thus data processing in an unusual information carrier is ensured (punched tape, diskette) or unusual peripheral device (such as a remote processor) without changes in the program, even in programs written in universal programming languages which do not contain this processing.

The operator controls the work of systems tasks for physical carry of data between disk and peripheral device using simple instructions. In data at the output this concerns start, stop or repeat. Somewhat more complicated is input. Input data should be prepared before starting the tasks (magnetic tapes etc. are set up), which is easily detected in data of the input flow of assignments, i.e., data containing task control operators. The proposed system, furthermore, supports the virtual processing of input data files, for example, from punched tape or other unusual information carrier. In the examples cited, the operator supports the start of the systems task for physical carry of data and, in addition to other parameters, defines the identifier of the input file. Task control operators designed to process the file refer to the identifier.

5. Program Systems

1. Supervisor. The supervisor of the proposed system consists of a comparatively small nucleus constantly stored in working memory and a large number of more or less independent subprograms transfered to working memory as needed by the page-by-page mechanism. The resident portion of the supervisor is located in virtual space in the SIA region and contains interrupt signal processing, subprograms, some of the most basic SVS subprograms, programs for magnetic disk readout error correction and, finally, programs necessary for operation of the page-by-page mechanism. In addition to the aforementioned subprograms, the resident portion contains the corresponding arrays.

The remaining programs of the supervisor are located in SVPS and are edited in turn in a single succession, so that any two subprograms from SVPS can operate as needed in an identical time segment.

In editing parts of the supervisor in SVPS, the editor forms a special list of all SVPS programs whose carry to working memory is done by the IPL program. Positions of this list contain SVPS phase names for each symbolic name, virtual address of the phase start in SVPS and address on the disk of the corresponding segment in the phase library. Summons of any part of SVPS is thus reduced to translation of the symbolic name to the corresponding virtual address and transmission of control to this address.

In combined operation with the task input control system, the supervisor can control the operation of up to five parallel executed independent user tasks; in each task the user can form and simultaneously execute up to 99 dependent subtasks.

Input of new phases during computation of results is done by two different methods in the system. The first method requires observation of the following agreements during phase formation:

phases are edited to the (virtual) address through which tasks will be written during execution (i.e., in entry of phases no site alignment is done). This condition is not difficult to observe, since each user task has its own virtual address space in the system;

the initial phase address is located at the segment boundary, i.e., two different phases of one task step are never edited into one segment. IN editing a large number of phases, gaps are formed in the virtual space. But in reality they only cause a loss of a certain number of virtual addresses which are consequently not physically depicted in either real memory or in disk storage. When the above agreements are observed, summons of a phase from the phase library is reduced to retrieval of the address of the phase start on the disk in the phase library and formation of the appropriate positions of segment and page arrays of PVS. Physical carry of required phase pages to real memory is done by the page-by-page mechanism in the same way as in the case of programs belong to SVPS. When agreements are not observed, i.e. if phase site alignmentis required during entry or the phase is not situated at the segment boundary, it should be read in the ordinary manner or its shape should be reproduced in disk storage. In the latter case system efficiency is reduced substantially.

2. Remaining Systems Programs

All other parts of the system are connected to the control program and the entire system via a conventional, accurately defined interface, primarily in symbolic form. References to the control system are always controlled using macroinstructions. Information contained in control arrays is also defined using macroinstructions or empty systems sections.

Concatenation of systems components is much simpler than in current systems. A basic condition for simplification is strict observance of all systems agreements. Basic systems agreements are expressed with the aid of standard media (subprograms, macroinstructions, etc.), whose use is obligatory for all systems components; LIOCS for systems files, program for readout and interpretation of control operators, program for communication with the operator and printout of errors, convention and macroinstructions of subprogram summons, formation of standard page headings.

The system is also provided with the following standard media for compilers:

readout and entry of library elements,
LIOC for translated programs,
dynamic signalization of translated program errors.

6. Input/Output System

One of the basic purposes in planning a system is to raise the flexibility of input/output and improve its efficiency in a virtual medium. The physical level of input/output in the proposed system is considered an exception. In cases of need, the user should support one of the following conditions:

a) either start the program in real memory mode;
b) or must fix pages containing the CCW chain and all regions of data himself, and transfer the data address in CCW to real himself (this method will be used in cases where the program generates the CCW chain). c) or the physical I/O program must always work with the virtual device.

The standard principle of I/O programming is the logical level (LIOC) (including systems programs). Principles of operation of virtual memory permit constant residence of executing modules of LIOC to be realized in virtual memory. They are carried into real memory as needed. Since the executing modules are multiple-input, they can be shared by several tasks, which involves substantial economy of space.

The module or a type of actual concatenated peripheral device can be considered simultaneously. Parameters of file description related to the specific device model do not have to be considered, like the parameters which determine only module properties.

The result of translation of the DTF description is an array containing CCB, parameter values, storage region for registers and module storage place of information necessary to the user, e.g. the address and length of a block just processed, a disk address, error display, etc. Working regions, place for CCW chains, IDAL, disk address field are specified during opening operation (OPEN). Necessary information is simultaneously fixed and translated to real. It is useful for the program not to contain a description of buffers, whose automatic specification and fixing occurs during opening via the macroinstruction GETVIS. Thus there is an economy of the number of fixed pages and space in the phase library, since the phase texts do not contain buffers.

If there is automatic specification of file buffers, further parameters such as block length can be dynamically altered when interaction with the file begins. In the proposed system it is possible to take the corresponding information either from DLBL/TLBL operators or from marker F1. Specification of the place for output files on the disk is also a function of the macroinstruction OPEN. Processing of disk markers guarantees the transferability of successive files from regular third-generation systems.

The format of index-sequenced files differs from current systems in that there is blocking of cylinder indexes of both primary data and data in the overflow region. When the file is formed, the user can determine the limits of reserved unoccupied place in each data block. In the case of overflow of the block its volume is divided roughly in half and a new block is formed with a reserve of unoccupied space in the overflow region. The proposed format, subjected in advance to simulation and tests, also supports addressing of blocks by means of their disk address (macroinstructions READ ID), which is especially important in data bank applications. In order to standardize data handling the parameter IOREG was introduced for a file with direct access (DTEDA) and some illogicalities were eliminated.

Working files (TYPEFLE-WORK) are generally appropriated by virtual memory as an information carrier instead of disk memory. For this case the system contains a special module which specifies the required volume of virtual memory and simulates in it the behavior of the disk module. This method also economizes and makes better use of disk space, acclerates work of translators and simlifies maintenance.

The proposed concept of virtual memory also supports the possibility of retaining some portion of virtual user space in a certain file which he specifies on disk memory. Thus it is a very efficient method of long-term storage of data for whose addressing a more complex method has to be used (lists, arrays, matrices, etc.). The program inquires for expansion of its virtual space by macroinstruction GETVIS and itself determines the symbolic device and identifier of the file in which the system will reproduce or whence will be selected samples of pages of the particular space.

Declarative and executive macroinstructions of LIOC on the symbolic level do retain the basic features from previous systems, but some parameters of file description are not taken into consideration. All methods of system expansion are planned not to disturb program compatibility.

The proposed concept greatly simplifies inclusion of new types of I/O devices into the system: until now this was considered a complex problem which required intervention into a large number of system components. In the proposed system this only concerns programs of physical and logical levels, but always in accurately defined places.

7. Library

All libraries of the proposed system are ordinary, standard organization disk files. A list is place first: its positions are sorted and blocked. To accelerate retrieval, each list block has a key. Positions whose cateloguing is done by the key are placed at the end of the list; total ordering and physical exclusion of dumped items is done during reorganization of the library, always associated with copying to increase system reliability. Some text is stored in constant length blocks (each text position is connected in sequential blocks). All libraries can be systemic and private.

The phase library occupies a particular place in the system. Phase texts are transfered from the phase library or using the page-by-page mechanism, or by ordinary methods (LOAD, FETCH) with possible site alignment. In addition to ordinary phases, the phase library contains declarative phases of user divisions, the systems library contains the list of shared space.

The length of blocks of all remaining libraries is identical, and their position may be of different type. In one library file may be stored modules, macroinstructions, initial texts and procedures; the type of position is defined by the identifier prefix. Access to libraries is done exclusively on the logic level, and its equpment is accessible to the user who can form his own libraries.

A general maintenance program for support of libraries performs cateloguing, dumping, correction, punching and printout of individual positions of entire groups. Inclusion of correction punchcards depends on their numbering in selected card columns. Using maintenance programs, it is possible even to write initial texts from parts of other texts in arbitrary sequence. In cataloguing macroinstructions, careful syntactical monitoring and preliminary processing into a form which greatly accelerates generation is done. Nonetheless even packaged macroinstructions can be corrected with auxiliary programs without preliminary downloading. The maintenance program used to copy and reorganize libraries makes a carry of whole libraries, sublibraries and groups of programs between magnetic disks or a magnetic disk and magnetic tape, namely from one or more input libraries to one output library. During this carry there is ordering and compression of text.

This solution is based on operating experience during which it has been found necessary to save at least one reserve copy of each library. In the proposed system one should use sequential distribution of libraries into systems and private libraries. Systems libraries are changed only in the event of a new editing of the system; a package with private library is always converted into a reserve copy after some time has elapsed and is copied and reorganized into a new working copy. This type of organization is always safe and convenient for computer maintenance.

8. Task Input and Planning Orders

Tasks are introduced into the system via one or more devices designated by the operator as systems inputs. If there are several systems inputs or there is a virtual device, the system operates in the multiprogramming mode. A systems input is a punched card reader, a magnetic tape or disk, a virtual device--an arbitrary device with paper medium, diskette or terminal.

The task planning unit is the order formed by one or more tasks which must be started in a specific sequence using identical systems resources. The order is started by the BATCH instruction, which can be considered a partition description. Parameters of this instruction describe the composition of peripheral devices and the requirement of the task for working memory. Descriptions of various compositions of peripheral devices are stored in the phase library: the BATCH instruction contains identifiers of the corresponding declarative phase. This phase serves the order dispatcher to pre-determine whether or not it has the required services available and whether or not it should write out it LUB array at the start of the order (standard reserving array). The user can reproduce, according to his needs, any number of declarative phases. Peripheral devices can be designed using all methods permitted in the instruction ASSGN (i.e. by means of address, class, list or package notation). All these devices are reinforced at startup for private use, except for magnetic disks which are only appropriated. Reinforcement occurs in the disks according to files only when the macroinstruction OPEN occurs.

The order dispatcher has an order list prepared for startup, and starts orders up according to priority and unoccupied resources. Since priority and the composition of required resources are properties of the order, and not invariably of the partitions set up, it makes sense to have a constant designation of partitions (BG, Fu). In connection with the operator, orders are also identified by means of their own identifiers and not by means of partition numbers. During order processing, the input position of orders is supplemented by data to define time expenditures and peripheral activity; after the order execution is completed, a job account is formed.

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ORBITS OF COMMUNICATIONS SATELLITES

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[Text] 4.3. The Orbital Structures of Communications Satellites

One of the basic requirements placed on satellite communications is 24-hour service and communications continuity.

The overall number of satellites in a system for servicing a territory, while providing continuity and 24-hour communications service is determined by the duration of a possible communications session (t_c) through each satellite of the system and depends on the size and position of this territory with respect to the satellite path on the surface of the earth.

The duration of a possible communications session is conditioned by the radio visibility time of the serviced territory as well as the possibility of providing a specified power flux density at the surface of the earth. As was noted above (see §3.5), the radio visibility time for "Molniya" type orbits is basically determined by the geographic positioning of the communications stations, which approximate the territory, by the Greenwich longitude of the ascending orbital node, as well as by the argument of the perigee.

The procedures set forth in §4.2 and 3.5 allow for the determination of the radio visibility time and service area from a satellite having any ascending node longitude and thereby establish the optimal, in the sense of a maximum radio visibility time and specified service area, ascending node longitude $\lambda^*_{\text{з}}$.

The duration of a communications session $t_c\ (\lambda^*_{\text{з}})$ obtained for the chosen optimal ascending node longitude permits the determination of the minimum number of satellites in the system:

$$n = E\left[\frac{T_1}{t_c(\lambda^*_{\text{з}})}\right] + 1, \qquad (4.30)$$

where E indicates the integer portion.

The selected number of satellites can provide for 24-hour communications over the territory under consideration. In this case, all of the satellites should have identical paths on the surface of the earth (i.e., identical orbital parameters and Greenwich longitudes of the ascending nodes) and follow one after the other at equal time intervals

$$\Delta t = T_3/n. \qquad (4.31)$$

The quantity Δp also determines the time during which the satellite should provide communications for the specified territory. It is obvious that $\Delta p \leq t_c(\lambda^*_э)$. Depending on the nature of the variation in the service time due to the Greenwich longitude of the ascending node, and the size of the difference $t_c(\lambda^*_э)$, Δt of the longitude of the orbital ascending nodes of the satellites in the system can vary within different limits, which are greater the greater the service time available $t_c(\lambda^*_э)$, Δt of the longitude of the orbital ascending nodes of the satellites in the system can vary within different limits, which are greater the greater the service time available $t_c(\lambda^*_э)$. The values of the boundaries for the permissible range of ascending nodal longitudes are determined by working from the assurance of communications continuity in the system.

A satellite in a "Molniya" type orbit makes two revolutions every 24 hours with ascending nodal longitudes spaced 180° apart.

If the orbital structure of the system of satellites in these orbits is soughtby working from the optimization of its characteristics during operation over one revolution, then the ascending node longitudes are equal to $\lambda^*_э$ and $\lambda^*_э + 180°$ respectively. In this case, we will call the revolution with the ascending node longitude which is optimal for the service area the main revolution, and the revolution following it, the trailing orbit.

To determine the possibility of using the satellite in the trailing orbit, the area is found which can be serviced during the time Δt by the satellite in the trailing orbit. In order to obtain as great an area as possible, the start of the communications session is optimized, beginning with the minimal possible start. The minimal possible start of a communications session is found just as for the case of the main orbit, by working from the operational conditions of the on-board equipment of the satellite, the time $\Delta t'$ to prepare it for operation and the positioning of the control points, if the satellite preparation for the start of a communications session is accomplished via commands from the ground. If at the point in time t(the orbital time for the entry of the control point into the satellite zone of radio visibility) an instruction is fed to prepare the satellite for service, then the possible minimum time for the start of a communications session will amount to $t + \Delta t'$.

By now defining the radio visibility zone (or the service zone) for the duration Δt sequentially for the points in time of the start of a communications session, beginning with $t + \Delta t'$ having a certain time spacing, we obtain the optimal start of a communications session in the trailing orbit.

The specific features of a "Molniya" type orbit and the geographic arrangement of the territory of the USSR permit the utilization of the main and trailing orbits for communications.

As an example, we shall consider a system consisting of four satellites with orbital parameters: $h_p = 500$ km; $T_\Omega = 11$ h 57 m 45 sec; $i = 63°$; $\omega = 285°$; $\lambda^*_з = 68°$ east longitude [e.l.].

For this system, communications time Δt is six hours. The southern boundary of the 24-hour service area of the satellite system in the main orbit is shown in Figure 4.6a, while the dashed line shows the service area in the trailing orbit.

As can be seen from Figure 4.6a, during the main orbit the territory of the USSR is provided with complete radio service. The six hour session of the trailing orbit provides for service to only a portion of the USSR. By comparing the areas serviced in the main and trailing revolutions, we note that part of the communications stations located in the combined service area of the main and trailing orbits can employ the satellites during both revolutions. The stations located in the shaded portion of the surface areas can use the satellites during only one of the revolutions.

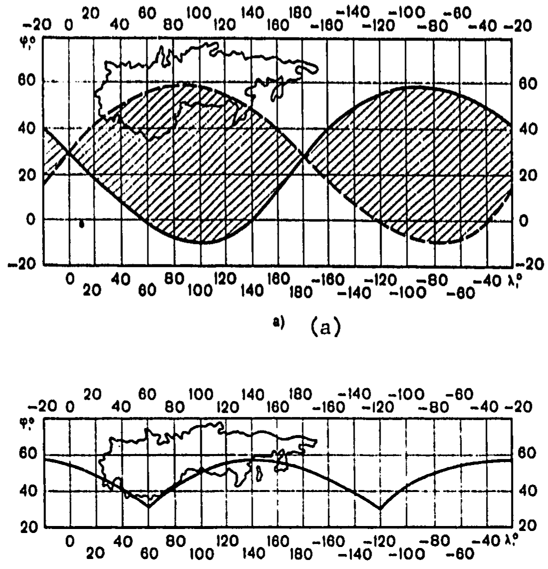
An example of a 24-hour service system using two satellites in orbits wtih the indicated parameters, with the exception of $\lambda_з$, is shown in Figure 4.6b.

Here, for the ground stations which are located north of the boundary of the service area of the satellites in the main and trailing orbits, 24-hour communications is provided by two satellites, where each of them operates for six hours in a revolution. The satellites should follow one another at a spacing of $T_\Omega/2$, and in this case, the stations operate alternately, first for 12 hours through the satellites during their flight in the main orbit, and then for 12 hours during their flight in the trailing orbit.

The longitudes of the ascending nodes of the main and trailing orbits, in order to assure the greatest surface area, should be arranged symmetrically with respect to the service area. In the example given here, the longitudes are 150° e.l. and 30° w.l.

To assure continuous service for a specified territory, all the satellites of the system should have identical paths, and consequently, identical Greenwich longitudes of the ascending orbital nodes. Then, in order to guarantee the requisite timewise shift for the passage of the equatorial plane, Δt, the orbital planes should be separated in absolute space under nominal conditions by the amount of $\Delta\Omega = 2\pi/n$ or $\omega_3 \Delta t = \Delta\Omega$ when using only the main orbit, and by the amount of $\Delta\Omega = \pi/n$ when using both revolutions.

Such a separation of the orbital planes in absolute space is assured through the appropriate selection of the launch times for placing the satellites in orbit in the process of setting up the system.



а) (a)

б) (b)

Figure 4.6. The 24-hour service area during the main and the trailing orbits for a system of four (a) and two (b) artificial earth satellites.

To determine the method of setting up a system of satellites which assure continuous service, it is convenient to introduce an idealized system. We shall understand such a system to be the orbital structure of satellites traveling in orbits, the ascending nodal longitudes of which are separated in absolute space in a uniform manner in a range of 0-360°, having a constant rate of precession, while the remaining parameters (inclination, altitude and argument of perigee, Greenwich longitude of the ascending node) coincide and remain constant during the existence of the satellites. By virtue of the assumptions made concerning the equality of the rates of precession of the longitudes of the ascending orbital nodes of all of the system satellites, and concerning their constancy, as well as concerning the unchanging nature of the remaining orbital parameters, including the Greenwich longitudes of the ascending nodes, the draconic orbital periods of the satellites will be stable and constant over the entire time of existence.

In such an orbital structure, the satellites pass through the same points of the orbit in equal time intervals (perigee, ascending node, apogee, etc.), i.e., synchronicity of satellite motion and constant conditions for the conduct of the communications sessions through each satellite are assured, while the orbital ascending node longitudes in absolute space always remain uniformly distributed over the range of 0--360°. The introduction of an idealized system permits a simplification of the process of setting up and refining an actual system, since the method of setting up actual systems in this case consists in assuring that an actual system is maximally close to the idealized one over the considered period of existence of the satellites.

We shall derive design formulas for the determination of the launch time of the satellites when setting up a system consisting of n satellites. We shall make use of the fact that the longitude of the orbital ascending node at the moment of insertion of the satellites, λ_B, coincides with the optimal value of $\lambda^*_З$, while the orbital period during the insertion provides for equal satellite paths. In the system under consideration, ballistic continuity of the possible communications sessions can be assured if the satellites will sequentially intersect the equator at the ascending node at time intervals of $2T_\Omega/n$, while the duration of the communications sessions through each satellite will be no less than $2T_\Omega/n$. If the satellites are inserted in orbit from one launch site during a 24-hour day in accordance with an unchanging plan and the time of travel from the moment of launch to arrival at the ascending node (Δt_a) remains constant for all satellites, then, obviously, to create an orbital structure for satellites with the conditions assumed above, the difference in the launch time of the satellites should be:

$$\Delta t_{\text{ст}} = 2T_\Omega/n. \tag{4.32}$$

After the satellites are in orbit, the longitudes of the orbital ascending nodes of the system satellites in absolute space will prove to be spaced apart by the angle:

$$\Delta\Omega = \Omega_2 - \Omega_1, \tag{4.33}$$

where

где where

$$\left.\begin{aligned} &\Omega_2 = S_0 + \lambda_в + \omega_З(t_{\text{ст}\,2} + \Delta t_а - \overset{hr}{3\text{ч}});\\ &\Omega_1 = S_0 + \lambda_в + \omega_З(t_{\text{ст}\,1} + \Delta t_а - \underset{hr}{3\text{ч}}) + \dot{\Omega}\Delta t_{\text{ст}};\\ &t_{\text{ст}\,2} = t_{\text{ст}\,1} + \Delta t_{\text{ст}}; \end{aligned}\right\} \tag{4.34}$$

Ω_2 is the longitude of the ascending node of the last satellite at the moment it arrives at the ascending node; Ω_1 is the longitude of the ascending node of the leading satellite, taking into account the precession of its orbital plane at the moment of passing through the ascending node of the next satellite; S_0 is the sidereal time at Greenwich midnight of the launch date;

$t_{ct\ 1}$ and $t_{ct\ 2}$ are the Moscow launch times for the leading and last satellites respectively.

By substituting the expressions for Ω_1 and Ω_2 in (4.33), taking (4.32) into account, we find:

$$\Delta\Omega = (\omega_3 - \dot{\Omega})\frac{2T_\Omega}{n}. \qquad (4.35)$$

Considering the fact that the stable orbital period T_{ct} (the draconic orbital period corresponding to the stable path) is defined taking (3.1) into account, with the expression:

$$T_\Omega = T_{\text{ст}} = \pi/(\omega_3 - \dot{\Omega}). \qquad (4.36)$$

we find that

$$\Delta\Omega = 2\pi/n. \qquad (4.37)$$

It follows from (4.37) that the launch time for each successive satellite of the system, consisting of n satellites, should be chosen from the condition that the longitudes of the ascending node of its orbit and the orbit of the leading satellite, taking the precession rate into account, are spaced an angle of $2\pi/n$ apart. As can be seen, in this formulation, to determine the launch time of the next satellite minimal information is required concerning the orbit of the preceding one, and specifically, only the value of the longitude of its ascending node at the moment of the impending passage of the equator by the satellite being launched, taking into account the rate of precession of the orbital planes.

Since the planes of the orbits of an idealized system have the same and constant rate of precession, the angle between the two adjacent orbital planes, which is obtained in designing the system, will be preserved throughout the entire time of functioning of the system. And since the orbital period of all satellites is equal to T_Ω, then there will also be preserved a constant interval in the time of equatorial passage by the satellites. This specific feature must be considered in setting up systems, when the setup is not completed within one 24 hour period, but is spaced over a longer period of time. Another approach is possible to the determination of the satellite launch time when establishing an orbital structure for satellites where $\lambda_B = \overset{*}{\lambda}_{\text{э}}$; $T_B = T_\Omega = T_{ct}$, if only the only the data and time of the launch of the previous satellite are known. In this case, for the launch date of the next satellite, it is necessary to find the time the preceding satellite passes through the equator in the main orbital revolution:

$$t_{\text{э}(i-1)} = t_{\text{ст}(i-1)} + \Delta t_{\text{э}} + (N-1)(T_\Omega - T_c/2) - \underset{hr}{24_{\text{ч}}}, \quad (4.38) \qquad (4.38)$$

where $t_{ct\,(i-1)}$ is the launch time of the preceding (i - 1)th satellite; T_c are solar days; N is the number of the main orbital revolution of the preceding satellite on the launch date of the next satellite; κ is an integer, determined from the equation:

$$\varkappa = E\left[\frac{t_{ct(i-1)} + \Delta t_s + (N-1)(T_\Omega - T_c/2)}{24}\right]$$

(E indicates the integer portion).

The launch time of the next satellite is determined from the expression:

$$t_{ct\,i} = t_{s(i-1)} - \Delta t_s \pm \Delta t_{ct} = t_{ct(i-1)} \pm \Delta t_{ct} + \\ + (N-1)(T_\Omega - T_c/2). \tag{4.39}$$

It can be shown that with this method of selecting the launch times, the difference in the values of the longitudes of the ascending nodes in absolute space, taking precession into account, will also amount to 2π/n.

On a certain date, the sidereal time at Greenwich midnight of which is equal to $S_{0(i-1)}$, let the (i - 1)th satellite of the system be launched at the point in time $t_{ct\,(i-1)}$. The ascending node longitude of its orbit during the first passage of the equator will be:

$$\Omega_{i-1} = S_{0(i-1)} + \omega_3(t_{ct(i-1)} + \Delta t_s - 3\text{h}) + \lambda_s. \tag{4.40}$$

Let the next satellite be launched after the preceding one has passed the ascending node in the N-th main revolution, the longitude of the ascending node of its orbit at the point in time of equatorial passage is:

$$\Omega_i = S_{0i} + \omega_3(t_{ct\,i} + \Delta t_s - 3\underset{\text{hr}}{\text{ч}}) + \lambda_s, \tag{4.41}$$

while the longitude of the ascending node of the orbit of the (i - 1)th object at this point in time is

$$\Omega_{i-1} = S_{0(i-1)} + \omega_3(t_{ct(i-1)} + \Delta t_s - 3\text{ч}) + \\ + \lambda_s + \dot{\Omega}[T_\Omega(N-1) + \Delta t_{ct}]. \quad \text{hr} \tag{4.42}$$

then
$$\Delta\Omega = S_{0i} - S_{0(i-1)} + \omega_3(t_{ct\,i} - t_{ct(i-1)}) - \\ - \dot{\Omega}[T_\Omega(N-1) + \Delta t_{ct}],$$

or taking (4.38), (4.32) and (4.36) into account, we find:

$$\Delta\Omega = S_{0i} - S_{0(i-1)} + \pi(N-1) + \frac{2\pi}{n} - \omega_3(N-1)\frac{T_c}{2}. \tag{4.43}$$

The mean Greenwich time at midnight on the launch date of the i-th satellite can be expressed in terms of the mean Greenwich time at midnight of the launch date of the (i - 1)th satellite using the formula:

$$S_{0i} = S_{0(i-1)} + \omega_3(T_c - T_3)\frac{N-1}{2}. \qquad (4.44)$$

Substituting (4.44) in (4.43), and considering the fact that $T_3\omega_3 = 2\pi$, we find $\Delta\Omega = 2\pi/n$, something which was asserted above.

The result obtained here attests to the complete equivalence of the solutions for the selection of the launch time of communications satellites in a "Molniya" type orbit in the two formulations described above.

The following conclusion follows from all that has been said above: if in an idealized system of n satellites in "Molniya" orbits, the ascending orbital nodes are spaced an angle of $2\pi/n$ apart, then the times when the satellites pass the equator are spaced $2T_\Omega/n$ apart regardless of the time interval used in setting up the system. In this case, the orbital periods of all the satellites of the system should coincide and be equal to the stable figure defined from formula (3.1).

All of the satellites of the system indicated here have coincident paths of travel of the point under the satellite on the surface of the earth and identical values of the Greenwich longitude of the ascending node, equal to λB.

If the satellite orbital insertion longitude λ_B does not agree with the optimal longitude of the ascending node λ_Ω^*, then the satellites must be launched with a lead correction with respect to the orbital period ΔT_B so that following the completion of N revolutions and the correction of the orbital period with the establishing of the stable orbit, the Greenwich longitudes of the ascending nodes of their orbits are equal to λ_Ω^*. In this case, a constant angle of $2\pi/n$ is preserved between the orbital planes if the difference in the time of equitorial passage by adjacent satellites is equal to $2T_\Omega/n$. We shall prove this, noting beforehand that the time of equatorial passage by satellites traveling in an orbit with a stable path ($T_\Omega = T_{ct}$) has a constant departure in the direction of an earlier time. In fact, the time a satellite passes through the N-th node can be represented in the form

$$t_{iN} = t_{i1} + (N-1)\left(T_\Omega - \frac{T_c}{2}\right) + \frac{T_c}{4}\left[1 + (-1)^N\right] - 24^{\text{hr}}\varkappa, \qquad (4.45)$$

where $\varkappa$ is an integer, determined from the equality:

$$\varkappa = E\left[\frac{t_{i1} + (N-1)\left(T_\Omega - \frac{T_c}{2}\right) + \frac{T_c}{4}\left[1 + (-1)^N\right]}{24}\right]$$

(E indicates the integer part, while the time is measured in hours).

We shall represent the draconic orbital period in the form

$$T_{\Omega} = T_{ct} + \Delta T_{B}. \tag{4.46}$$

After substituting (4.46) in (4.45), we obtain

$$t_{BN} = t_{B1} + (N-1)\left(T_{ct} + \Delta T_{B} - \frac{T_c}{2}\right) + \frac{T_c}{4}[1 + (-1)^N] + 24\underset{hr}{ч}\varkappa. \tag{4.47}$$

In the case where $\Delta T_B = 0$, i.e., when $T_{\Omega} = T_{ct}$:

$$t_{BN} = t_{B1} + (N-1)\left(T_{ct} - \frac{T_c}{2}\right) + \frac{T_c}{4}[1 + (-1)^N] + 24\overset{hr}{ч}\varkappa. \tag{4.48}$$

As can be seen from (4.48), the time a satellite passes the equator moving in an orbit with a stable path, there is a deviation in the direction of an earlier time ($T_{ct} < T_c/2$) by the amount of $\Delta t = T_{ct} - T_c/2$ per revolution.

When $\Delta T_B \neq 0$, there occurs an additional deviation in the time of equatorial passage, equal to ΔT_B per revolution.

We shall find the relationship between the additional displacement of the satellite in the time of equatorial passage and the departure of the longitude of the node relative to the Greenwich system.

We shall designate the difference in the Greenwich longitudes of the N-th and the first of the ascending nodes as $\Delta\lambda_{з}$. Then:

$$\Delta\lambda_{з} = (N-1)\,\Delta T_{B}(\omega_3 - \dot{\Omega}) - \frac{\pi}{2}[1 + (-1)^N]\,\mathrm{sign}\,|\Delta T_{B}|.$$

From this we find:

$$(N-1)\,\Delta T_{B} = \frac{\Delta\lambda_{з}}{\pi}T_{ct} + \frac{T_{ct}}{2}[1 + (-1)^N]\,\mathrm{sign}\,|\Delta T_{B}|. \tag{4.49}$$

Substituting (4.49) in (4.47), we obtain a formula for the determination of the shift in the time of passage of the N-th node relative to the first:

$$\Delta t_{BN} = \left(T_{ct} - \frac{T_c}{2}\right)(N-1) + \frac{\Delta\lambda_{з}}{\pi}T_{ct} + \frac{T_{ct}}{2}[1 + (-1)^N]\,\mathrm{sign}\,(\Delta T_{B}) + \frac{T_c}{4}[1 + (-1)^N] + 24\overset{hr}{ч}\varkappa. \tag{4.50}$$

As can be seen from (4.50), besides the constant timewise shift in equatorial passage, related to the difference in the draconic period from half of a solar day, there occurs an additional shift equal to $\Delta\lambda_{з}T_{ct}/\pi$, which depends only on the amount of departure of the ascending node longitude $\Delta\lambda_{з}$. Since this shift does not depend on the number of the revolution, then in a system of n satellites, the longitudes of the ascending nodes of which on a particular date following the completion of the insertion process assume values of $\lambda^{*}_{з}$, the same timewise shift in equatorial passage will occur for each satellite. This shift will have no effect on the interval at which the satellites follow one another, i.e., it will remain the same as it was for the case of insertion into a stable period and at the insertion longitude, which is equal to the optimal longitude. But for this case, it was shown above that the orbital planes remain spaced $2\pi/n$ apart if the time when the satellites pass the equator relative to each other is $2T_{\Omega}/n$ regardless of the length of time in the process of setting up the system. The assertion formulated above is thus proved. If we now equate the longitude of the ascending node of the orbits of an idealized system to the longitude of the ascending node of actual systems, then all of the conclusions derived here can be employed in the design of actual satellite communications systems. The design of a system can start at any launch date for the first satellite into one of the planes with an arbitrary longitude Ω_1. Moscow launch time is defined in accordance with (4.34) from the formula

$$t_{ст\,1} = \frac{\Omega_1 - S_0 - \lambda_{в}}{\omega_3} - \Delta t_{в} + 3\,\text{ч}. \qquad (4.51)$$

At the start of the N-th revolution, the longitude of the ascending node of this satellite orbit will amount to

$$\Omega_1(N) = \Omega_1 + \dot{\Omega} T_{ст}(N-1). \qquad (4.52)$$

If the i-th satellite is to be launched on the date corresponding to the N-th revolution of the first satellite, then in accordance with that presented above, it is sufficient to provide for its insertion into the plane with a longitude of the ascending node determined from the formula:

$$\Omega_i = \left\{\Omega_1 + \dot{\Omega} T_{ст}(N-1) + \frac{2(\pi + \dot{\Omega} T_{ст})}{n}(i-1)\right\}_{0-2\pi}. \qquad (4.53)$$

The last term characterizes the shift in the orbital plane of the i-th satellite relative to the plane of the first, and $\{\ \}_{0-2\pi}$ signifies the result of referencing the angle to the 0--2π range. Then the launch time for the i-th satellite will be defined by the expression:

$$t_{ст\,i} = \frac{\Omega_i - S_{0i} - \lambda_{в}}{\omega_3} - \Delta t_{в} + 3\,\text{ч}, \qquad (4.54)$$

where S_{0i} is the sidereal time at Greenwich midnight of the launch date. Expression (4.54) can be transformed, by switching from the use of (4.44) from S_{0i} to the sidereal time on the launch date for the first satellite and employing (4.53), to the form:

$$t_{ст\,i} = \left\{\frac{\Omega_0 - S_0 - \lambda_{в}}{\omega_3} - \Delta t_{в} + 3\underset{\text{hr}}{\text{ч}} + \frac{2T_{ст}}{n}(i-1) + \right. \qquad (4.55)$$
$$\left. + \left(T_{ст} - \frac{T_c}{2}\right)(N-1)\right\}_{CD}.$$

The resulting expression coincides with (4.39); $(\ )_{CD}$ means that the result is referenced to Moscow time. We will note that (4.55) provides for the determination of the launch time when completing the system.

6.2. The Determination of the Service Areas and the Radio Interference Taking into Account the Errors in the Orientation of the On-Board Transmitting Antenna

The method of calculating the service area of a stationary satellite treated in the preceding section does not take into account the errors of the orientation of the on-board transmitting antenna. In actual fact, such errors always exist, and it is quite understandable that they should be considered when determining the characteristics of a communications system.

If the on-board antenna is rigidly mounted in the satellite, then the precision of its orientation is completely determined by the precision in the orientation of the satellite.

For an antenna having a drive which can be oriented independently of the satellite towards the service area, the precision in its orientation is determined by the characteristics of the antenna guidance system itself.

We shall introduce an orbital system of coordinates: SXYZ. We shall place the origin of the coordinates in the center of mass of the satellite, direct the SX axis along the radius vector towards the center of the earth, and direct the SZ axis along the transversal in the direction of motion of the satellite. The SY axis completes the system. Let the satellite in its travel in the orbit be oriented with one of the axes towards the center of the earth, with a precision characterized by rotations with respect to the SZ axis through an angle $N_{k.0}$ (roll angle), with respect to the SY axis through an angle $N_{t.0}$ (pitch angle) and with respect to the SX axis through an angle $N_{p.0}$ (yaw angle), and let the on-board antenna be rigidly coupled to the satellite, while the axis of its directional pattern is directed towards a point C on the earth's surface having geographic coordinates of ϕ_c and λ_c. The direction of its axis in this case can be determined by the angles ξ and η.

The angle ξ is the angle between the plane $Y = 0$ (the plane of the orbit) and the plane passing through the SZ axis and the point C. The angle η is the angle between the plane $Z = 0$ and a straight line passing through the points S and C.

Because of errors in the orientation of the satellite, the axis of the on-board antenna in the general case describes a complex figure, which can be approximated by a pyramid with the vertex at the point S and with angles at the vertex of N_t and N_k (Figure 6.6). These angles determine the deviations of the antenna axis with respect to pitch and roll respectively, where the angle N_k characterizes the shift of the on-board antenna axis in the north-east direction, while the angle N_t applies to the east-west direction relative to the direction SC. We shall assume that the angle N_k is positive when the antenna axis is inclined to the north from the SZC plane, while the angle N_t is positive when the direction of the antenna axis is inclined to the east from the SYC plane. The values N_k and N_t, depending on the angles ξ, η and the precision in the orientation of the N_t, N_k and N_p axes of the satellite can be derived from the following expressions

$$\left.\begin{aligned}
N_{\text{т}} &= N_{\text{т.o}} + \eta - \\
&- \operatorname{arctg}\left[\frac{\sin\eta\cos\xi - \sin\eta\cos\xi\,(1-\cos N_{p.o}) -}{\cos\xi\cos\eta}\ldots\rightarrow\right. \\
&\qquad\left.\ldots\rightarrow\frac{-\sin\xi\sin N_{p.o}}{\cos\xi\cos\eta}\right]; \\
N_{\text{к}} &= N_{\text{к.o}} + \xi - \\
&- \operatorname{arctg}\left[\frac{\sin\xi\cos\eta - \sin\xi\,(1-\cos N_{p.o}) -}{\cos\xi\cos\eta}\ldots\rightarrow\right. \\
&\qquad\left.\ldots\rightarrow\frac{-\sin\eta\cos\xi\sin N_{p.o}}{\cos\xi\cos\eta}\right].
\end{aligned}\right\}\ (6.23) \qquad (6.23)$$

In the case of the absence of satellite orientation errors with respect to the yaw channel ($N_{p.0} = 0$), the errors in the orientation of the satellite are converted directly to orientation errors of the on-board antenna.

Expressions (6.23) for several estimates can be simplified by means of replacing the trigonometric functions of small angles, x, by their arguments:

$\sin x \approx x$, and $\cos x \approx 1 - x^2/2$.

Such a substitution can be made even for the angles ξ and η, since their values will not exceed 8° in the majority of cases. Then, taking what has been said into account, it follows from (6.23) that:

$$N_{\text{т}} = N_{\text{т.o}} + \xi N_{p.o}; \quad N_{\text{к}} = N_{\text{к.o}} + \eta N_{p.o}. \qquad (6.24)$$

For antennas which have a drive, the precision in the orientation of the on-board transmitting axis is specified directly by the values N_t, N_k and N_p, which are determined by the characteristics of the system. When the axis of the antenna is moved within the limits of the angles N_t and N_k there always exists for each angle α^*_{ij}, which defines the position of the points N_{ij}, one worst case position of the antenna axis, defined by the conditions:

$$\operatorname{sign} N_{\text{к}} = -\operatorname{sign}(\cos\alpha^*_{ij}); \ \operatorname{sign} N_{\text{т}} = \operatorname{sign}(\sin\alpha^*_{ij}). \qquad (6.25)$$

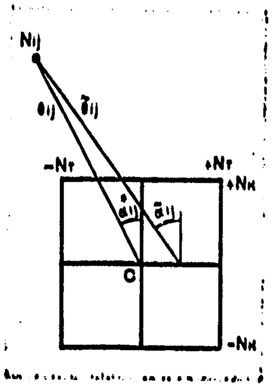


Figure 6.7. On the determination of the worst case orientation of the antenna axis.

We shall now consider a certain point N_{ij} (see Figure 6.2). The gain of the on-board antenna in the direction towards the point N_{ij} is defined in terms of the angles θ_{ij}, α_{ij} and α_k, if it is assumed that the axis of the antenna is directed towards the point C. If orientation errors N_t and N_k are brought into consideration, then the possible direction of the antenna axis can be schematically bounded by a rectangle having sides in angular measure of $2N_t$ and $2N_k$ in some plane perpendicular to the line SC (Figure 6.7). Then the angles $\overset{*}{\alpha}_{ij}$ and θ_{ij}, which are depicted schematically in Figure 6.7, will correspond to the nominal orientation of the antenna axis towards the point C. The worst case point for the direction of the antenna axis when determining the gain in the direction to the point N_{ij} will be the point of the rectangle obtained in accordance with (6.25). To determine the gain of the on-board antenna in the direction towards the point N_{ij}, taking into account the orientation errors N_t and N_k, it is necessary to determine the angles $\tilde{\theta}_{ij}$ and $\tilde{\alpha}_{ij}$, corresponding to the worst case position of the antenna axis.

The expressions for the determination of $\tilde{\theta}_{ij}$ and $\tilde{\alpha}_{ij}$ have the form

$$\left.\begin{aligned}
&\cos\tilde{\theta}_{ij} = \\
&= \cos\theta_{ij}\,\frac{1-\operatorname{tg}N_T\operatorname{tg}\theta_{ij}|\sin\overset{\bullet}{\alpha}_{ij}| - \operatorname{tg}N_K\operatorname{tg}\theta_{ij}|\cos\overset{\bullet}{\alpha}_{ij}|}{\sqrt{1+\operatorname{tg}^2N_T+\operatorname{tg}^2N_K}};\\
&\cos\tilde{\alpha}_{ij} = \\
&= \frac{\operatorname{tg}\theta_{ij}\cos\overset{\bullet}{\alpha}_{ij}+\operatorname{tg}N_K}{\sqrt{(\operatorname{tg}\theta_{ij}|\sin\overset{\bullet}{\alpha}_{ij}|+\operatorname{tg}N_T)^2+(\operatorname{tg}\theta_{ij}|\cos\overset{\bullet}{\alpha}_{ij}|+\operatorname{tg}N_K)^2}};\\
&\sin\tilde{\alpha}_{ij} = \\
&= \frac{\operatorname{tg}\theta_{ij}\sin\overset{\bullet}{\alpha}_{ij}+\operatorname{tg}N_T}{\sqrt{(\operatorname{tg}\theta_{ij}|\sin\overset{\bullet}{\alpha}_{ij}|+\operatorname{tg}N_T)^2+(\operatorname{tg}\theta_{ij}|\cos\overset{\bullet}{\alpha}_{ij}|+\operatorname{tg}N_K)^2}}.
\end{aligned}\right\}\tag{6.26}$$

(6.26)

The angles θ_{ij} and $\overset{*}{\alpha}_{ij}$ which enter into the expressions of (6.26) are determined from (6.12) and (6.13). The condition which determines the boundary of the service area in the direction with an azimuth A_i from the center of the orientation, which is similar to the condition (6.18) of §6.1, can be written:

$$|\tilde{\Theta}_{ij} - \Theta_{\tau p}(\alpha_{ij})| \leqslant \varepsilon. \tag{6.27}$$

To determine α_{ij}, it is necessary to consider the precision in the orientation of the antenna as regards yaw (rotation about the line SC):

$$N_p = N_{p.0}$$

and the possible structural design angle for the turning of the antenna on its axis.

The necessity of structurally turning the antenna can be due to either the configuration of the service area with respect to the position of the satellite, or the necessity of satisfying several limitations. The quantity α_{ij} is determined from the relationship:

(6.28)

$$\alpha_{ij} = (\tilde{\alpha}_{ij} - \alpha_{ij}^{*}) N_p \operatorname{sign}[\sin(\tilde{\alpha}_{ij} - \alpha_k)\cos(\tilde{\alpha}_{ij} - \alpha_k)] \quad (6.28)$$

when при $|\sin(\tilde{\alpha}_{ij} - \alpha_k)| > \sin N_p$ (6.29)

and и $\sin \alpha_{ij} = 0$ (6.29)

when при $|\sin(\tilde{\alpha}_{ij} - \alpha_k)| < \sin N_p$

$$\operatorname{sign}(\cos \alpha_{ij}) = \operatorname{sign}[\cos(\tilde{\alpha}_{ij} - \alpha_k)].$$

The supplemental term $N_p \operatorname{sign}[\sin(\tilde{\alpha}_{ij} - \alpha_k)\cos(\tilde{\alpha}_{ij} - \alpha_k)]$ yields a reduction or an increase in the angle $\tilde{\alpha}_{ij}$ by the amount of the precision in the orientation with respect to the yaw channel in such a manner that the antenna gain is the lowest. Expression (6.29) means that if within a precision of N_p the minor semi-axis of the directional pattern coincides with the point N_{ij}, then the angle α_{ij} is to be taken as equal to either 0 or 180°, so that the antenna gain is the lowest. All the remaining conditions, as, for example, the condition of assuring an elevation of no less than the permissible γ_0, should be met. We will note that if it proves possible to determine the gain of the antenna analytically as a function of θ_{ij} and α_{ij}, then condition (6.27) is to be reduced to the form:

$$|G(\tilde{\Theta}_{ij}, \alpha_{ij}) - G_{\tau p}(D_{ij}, \gamma_{ij})| \leqslant \varepsilon.$$

where D_{ij} and γ_{ij} are found from (6.17).

The method remains justified for asymmetrical directional patterns. In this case, it is sufficient to change (6.2) in an appropriate manner, retaining the correspondence of the small aperture of the directional pattern to the value of the angle $\alpha = 0$.

Along with the problem of determining the reliable reception area (the service area), there is also substantial interest in the problem of finding the radio interference region produced by ground services, especially when using high power satellites in the communications system, for example, those which provide for the reception of a television signal directly at the home antennas of users.

The permissible interfering signal level is regulated by the norms of the VAKR [Worldwide Administrative Radio Communications Conference on Space Communications] [23]. This level depends on the broadcast frequency and is a function of the angle to the local horizon at which the interfering signal arrives at the point under consideration.

Up to a certain value of the elevation angle γ, a constant power flux density is permitted, and thereafter, with an increase in γ, the permissible value of the power flux density increases by virtue of the spatial selection of the interfering signal and the received useful signal, radiated by another ground station. Thus, for example, in accordance with VAKR stamdards [23], the interfering power flux density of the interfering signal at the surface of the earth at a frequency of 300 MHz should satisfy the following conditions:

$$-129\ \text{dBW/m}^2 \quad \text{at} \quad \gamma \leq 20^\circ;$$
$$-129\ \text{dBW/m}^2 + 0.4(\gamma - 20^\circ) \quad \text{at} \quad 20^\circ < \gamma \leq 60^\circ;$$
$$-113\ \text{dBW/m}^2 \quad \text{at} \quad \gamma > 60^\circ.$$

The methods presented in §6.1 and 6.2 can be employed to calculate the radio interference area, taking the following into account. Since when calculating the radio interference zone it is necessary to place an upper limit on the level of the interfering signal, the precision in the orientation with respect to pitch, roll and yaw is to be chosen so that the antenna gain in the direction towards the point under consideration is the highest. For this reason, when the following conditions are met:

$$|\sin\theta_{ij}\sin\overset{\bullet}{\alpha}_{ij}| > |\sin N_{\text{т}}|$$

и and

$$|\sin\theta_{ij}\cos\overset{\bullet}{\alpha}_{ij}| > |\sin N_{\text{к}}|$$

The following expressions are to be used for the determination of $\tilde{\theta}_{ij}$ and $\tilde{\alpha}_{ij}$:

$$\left.\begin{aligned}
&\cos\tilde{\theta}_{ij} = \cos\theta_{ij}\times \\
&\times\frac{1+\operatorname{tg}N_{\text{т}}\operatorname{tg}\theta_{ij}|\sin\overset{\bullet}{\alpha}_{ij}| - \operatorname{tg}N_{\text{к}}\operatorname{tg}\theta_{ij}|\cos\overset{\bullet}{\alpha}_{ij}|}{\sqrt{1+\operatorname{tg}^2N_{\text{т}}+\operatorname{tg}^2N_{\text{к}}}}; \\
&\cos\tilde{\alpha}_{ij} = \\
&= \frac{\operatorname{tg}\theta_{ij}\cos\overset{\bullet}{\alpha}_{ij} - \operatorname{tg}N_{\text{к}}}{\sqrt{(\operatorname{tg}\theta_{ij}|\sin\overset{\bullet}{\alpha}_{ij}| + \operatorname{tg}N_{\text{т}})^2 + (\operatorname{tg}\theta_{ij}|\cos\overset{\bullet}{\alpha}_{ij}| + \operatorname{tg}N_{\text{к}})^2}}; \\
&\sin\tilde{\alpha}_{ij} = \\
&= \frac{\operatorname{tg}\theta_{ij}\sin\overset{\bullet}{\alpha}_{ij} - \operatorname{tg}N_{\text{т}}}{\sqrt{(\operatorname{tg}\theta_{ij}|\sin\overset{\bullet}{\alpha}_{ij}| + \operatorname{tg}N_{\text{т}})^2 + (\operatorname{tg}\theta_{ij}|\cos\overset{\bullet}{\alpha}_{ij}| + \operatorname{tg}N_{\text{к}})^2}}.
\end{aligned}\right\} \qquad (6.30)$$

If only the following condition is met,

$$|\sin\theta_{ij}\sin\overset{\bullet}{\alpha}_{ij}| \leqslant |\sin N_{\text{т}}|,$$

Then the values of $\tilde{\theta}_{ij}$ and $\tilde{\alpha}_{ij}$ must be found from the formulas:

$$\left.\begin{aligned}&\cos\tilde{\theta}_{ij}=\cos\theta_{ij}\frac{1+\operatorname{tg}N_{\text{к}}\operatorname{tg}\theta_{ij}}{\sqrt{1+\operatorname{tg}^2N_{\text{т}}+\operatorname{tg}^2N_{\text{к}}}};\\&\sin\tilde{\alpha}_{ij}=0;\\&\operatorname{sign}(\cos\tilde{\alpha}_{ij})=\operatorname{sign}(\cos\overset{\bullet}{\alpha}_{ij}).\end{aligned}\right\}\qquad(6.31)$$

And finally, when the following condition is met:

$$|\sin\theta_{ij}\cos\overset{\bullet}{\alpha}_{ij}| \leqslant |\sin N_{\text{к}}|$$

The following relationships should be employed to compute $\tilde{\theta}_{ij}$ and $\tilde{\alpha}_{ij}$:

$$\left.\begin{aligned}&\cos\theta_{ij}=\cos\tilde{\theta}_{ij}\frac{1+\operatorname{tg}N_{\text{т}}\operatorname{tg}\theta_{ij}}{\sqrt{1+\operatorname{tg}^2N_{\text{т}}+\operatorname{tg}^2N_{\text{к}}}};\\&\cos\tilde{\alpha}_{ij}=0;\\&\operatorname{sign}(\sin\tilde{\alpha}_{ij})=\operatorname{sign}(\sin\overset{\bullet}{\alpha}_{ij}).\end{aligned}\right\}\qquad(6.32)$$

6.3. The Determination of the Requisite Directional Pattern and Setting Angles for the On-Board Antenna

To select the preliminary characteristics of the directional pattern of the on-board antennas of a stationary satellite and determine their setting angles on the satellite, it is convenient to represent the surface of the globe visible from the stationary satellite in spherical coordinates, related to the satellite.

We shall introduce a spherical system of coordinates, and place the origin of the system in the center of mass of the satellite S. We shall pass the plane SOP through the point S and the rotational axis of the earth (Figure 6.8). We shall define the position of any point N on the surface of the earth in the system of coordinates introduced here in terms of the angle α and β. The angle α represents the angle between the plane SOP and the plane passed through the points S and N perpendicular to the equatorial plane. The angle α is positive for points on the earth's surface, which are located to the east of the meridian below the satellite and negative for

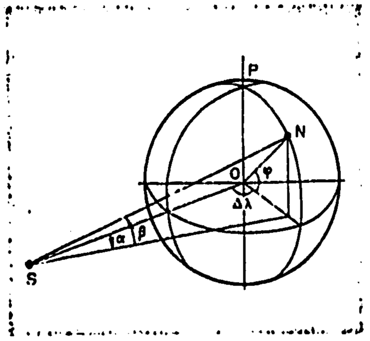


Figure 6.8. The spherical system of satellite coordinates.

points located to the west of the meridian below the satellite. The angle β is the angle between the direction to the point N on the earth's surface and the equatorial plane. Then the entire surface of the globe visible from a stationary satellite can be represented in a coordinate grid of α and β in the following manner. For the coordinates ϕ, λ and R of any point on the earth's surface, α and β can be determined in accordance with Figure 6.8 from the formulas:

$$\left.\begin{aligned}\beta &= \operatorname{arctg}\frac{R\sin\varphi}{d};\\ \alpha &= \arcsin\frac{R\cos\varphi\sin\Delta\lambda}{d},\end{aligned}\right\} \qquad (6.33)$$

where

$$d=\sqrt{r^2+R^2\cos^2\varphi-Rr\cos\varphi\cos\Delta\lambda};\quad \Delta\lambda=\lambda-\lambda^*;$$

ϕ is the geocentric latitude of the point N at the earth's surface.

Because of the simplified model for the determination of the on-board antenna characteristics, one can adopt the geographic latitude in place of the geocentric and the average value of the radius vector of the point on the earth's surface in place of its true value. In this case, the error in the coordinates α and β will not exceed 1.5'. Using formulas (6.33), all the meridans and parallels can be represented in the coordinates α and β. In a similar manner, lines of equal ranges or elevation angles can be drawn on the coordinate grid, which take the form of circles concentric to the circle of the outer outline of the earth. The radius in angular measure of circles of equal ranges and elevation angles can be determined in accordance with Figure 6.9 from the relationships:

$$\begin{aligned}\delta &= \arcsin\left(\frac{R}{d}\sin\varphi\right);\\ d &= \sqrt{r^2+R^2-Rr\cos\varphi};\quad \gamma=90^\circ-\varphi-\delta.\end{aligned} \qquad (6.34)$$

In this case, a point with a latitude ϕ is chosen at the meridian of the point beneath the satellite. Then, the following expression can be used to find the relationship between α and β, which corresponds to equal range d and elevation angle γ:

$$\cos\alpha=\cos\delta/\cos\beta \qquad (6.35)$$

or, considering the small size of the angles α, β and δ, one can write approximately:

$$\alpha^2+\beta^2=\delta^2. \qquad (6.36)$$

Expression (6.36) provides an error of no more than 1' in the determination of the angles α and β. The coordinate grid of the visible portion of the globe plotted in this manner is depicted in Figure 6.10.

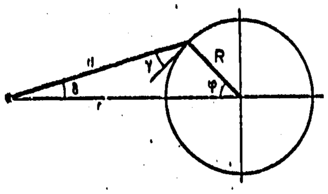


Figure 6.9. On the construction of lines of equal ranges and elevation angles.

The lines of the angular dimensioned grid of the spherical system of coordinates referenced to the satellites are indicated with the letters D and E in Figure 6.10, along the horizontal and vertical respectively. The parallels are represented by the B lines and the meridians by the C lines. The lines of equal ranges and elevation angles are designated by the letter A.

It should be emphasized that the lines of the requisite gains coincide with the lines of equal ranges and elevations.

An territory of the earth's surface visible from the satellite can be mapped in the α and β coordinate system. Thus, the territory of the Soviet Union, visible from a stationary satellite located at 100° east longitude is depicted in Figure 6.11.

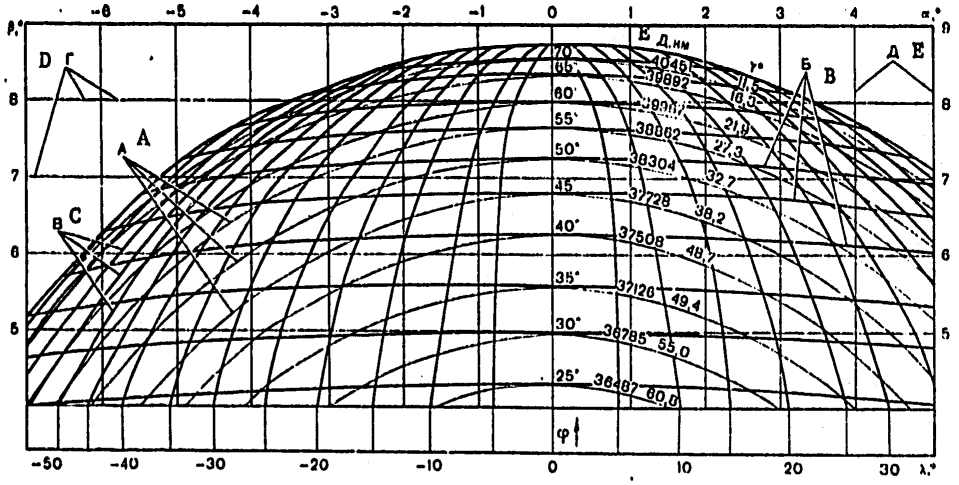


Figure 6.10. The earth in a spherical system of coordinates referenced to the satellite.

Now let it be necessary for the servicing of a certain area to determine the approximate characteristics of the directional pattern.

The aperture defined with respect to α and β corresponds to the specified territory to be serviced and referenced to the coordinates α and β. Thus, a solid angle aperture with respect to α of 3° and with respect to β of 1.5° corresponds to the portion of the territory of the USSR lying between 85° east longitude and 115° east longitude for a satellite at 100° east longitude.

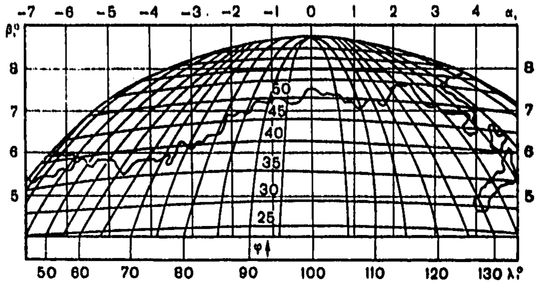


Figure 6.11. The territory of the USSR in a spherical system of coordinates referenced to a satellite ($\lambda^* = 100°$ east longitude).

The resulting value for the solid angle aperture should correspond to the aperture of the directional pattern of the on-board transmitting antenna. The gain in the aperture is defined with respect to the reception area at the maximum reception range and to the corresponding minimal elevation angle at the reception point. In this case, it is determined by the range and the elevation corresponding to the point in the territory with the greatest value of the angle β. In this case, the aperture of the directional pattern must be increased by the amount of the orientation error.

Simultaneously with this, the coordinates of the point on the earth's surface towards which the electrical axis of the directional pattern of the on-board antenna and the setting angle of the antenna in the satellite should be directed, can be determined in a first approximation. For example, if the system SXYZ is chosen as the satellite system of coordinates, where the SX axis is directed towards the center of the earth, the SZ axis is directed along the binormal to the orbit and the SY axis completes the system making it rectilinear, then the antenna mounting can be specified with three angles: the two angles ξ and η for the corresponding center of orientation and by the angle α_k, the angle of antenna rotation with respect to the directional pattern. Thus, for our example, the axis of the on-board antenna directional pattern should be aimed at the point with coordinates of $\phi \approx 57°$ north latitude, $\lambda = 100°$ east longitude, while the on-board antenna should be mounted so that the axis of the directional pattern is $\xi = 7° 45'$ and $\eta = 0$ (in this case, $\alpha = 0$). In this instance, it is not at all necessary that the serviced area be arranged symmetrically with respect to the meridian beneath the satellite. In this case, the center of the orientation is chosen in a similar fashion, while the direction of the electrical axis of the on-board directional pattern is assured by the appropriate mounting of the antenna with respect to the axes of the satellite.

When it is necessary to consider limitations on the radiated signal power (in accordance with the requirements stipulated by various accords) for a certain territory, determined by the coordinates ϕ and λ, limitations on the power of the on-board transmitting antenna can be drawn in figures such as delineated in Figure 6.11 using type A curves for the corresponding values of ϕ and λ.

In order to show the advantage of the representation given here for the portion of the earth's surface visible from a satellite, lines of observation angles from a satellite located at 100° east longitude are shown in Figure 6.12 (lines of an angular dimensioned grid of the spherical system of satellite coordinates), for the semi-conical projection of the visible portion of the northern hemisphere. Although this representation yields the same functions as those shown in Figure 6.12, it is a more complex matter to use this representation.

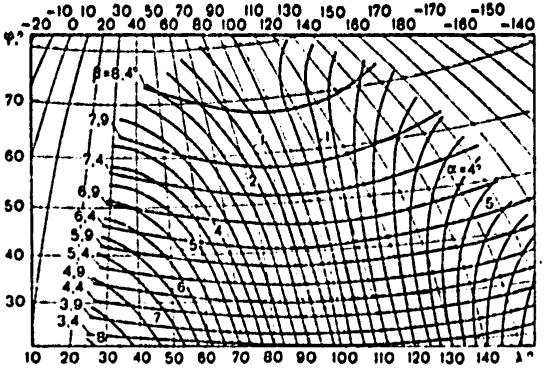


Figure 6.12. Lines of observation angles from a satellite ($\Delta^* = 100°$ east longitude).

The directional pattern obtained using the described approach should be made more precise taking into account the possible variants of the design using the numerical methods of analysis and calculation described in the preceding sections of this chapter. In this case, the problem of more precisely specifying the antenna setting angles ξ and η or the position of the center of orientation and the antenna rotation angle α_k is also solved. In the general case, when selecting the center of orientation, the area of the reliable reception zone serves as the optimality criterion. In this case, there always exists a number of limitations of the inequality type on the parameters or their functions. Because of the impossibility of deriving any kind of analytical estimates, the solution is accomplished numerically.

Assuming, for example, that of the three independent parameters which determine the pattern, two are constant, one can derive the area of the service zone as a function of the third taking the limitations into account. This function defines the simultaneously permissible range of change in the third parameter, for example, α_k. By varying the values of the coordinates of the center of orientation in the appropriate fashion (the values of the two setting angles for the on-board antenna), one can obtain the permissible values of α_k for any combinations of ξ and η.

7.3. The Coordination of the Angular Spacings Between Communications Satellites

The extremely saturated radio band in the 1-10 GHz frequency range is employed for contemporary satellite communications [1-3]. The use of this band is due to the minimal influence on signal passage via earth to space and space to earth signals of the interference generated by natural sources of earth and extraterrestrial origin as well as industrial noise. Moreover, this band is maximally well mastered and rather intensively utilized by traditional communications services.

Under these conditions, the problem of crosstalk interference of not only the different communications services, but also within satellite communications is extremely acute. To assure normal operation of the communications equipment which functions in one band or another, limitations are placed on the technical parameters, the layout, and the operational sequence of the satellite communications components, including the satellites themselves.

The question of crosstalk is an urgent one not only for systems which employ satellites in stationary orbits, because of the limited capabilities of an equatorial orbit with respect to the number of satellites which can be placed in it, but also for systems which use satellites in high elliptical orbits.

The visible trajectories of satellites against the celestial sphere of ground stations are shown in Figures 7.7 and 7.8 for "Molniya" type orbits in a topocentric system of coordinates, i.e., in coordinates of azimuth (A) and elevation angle (γ). The direction of satellite travel against the celestial sphere of the tracking station is shown with the arrow on each curve. The times in hours, read out from the point in time the satellites pass through the orbital perigee, are indicated with the dots on the curves.

Considering the fact that the satellites in the system follow each other along the same paths, they will have identical tracks against the celestial sphere for the point under consideration. Therefore, as can be seen from the figures, there is always a situation in which the angular spacings between the satellites following one another are small. For example, such a configuration between rising and setting satellites at the moment the ground station switches over from one satellite to the other can lead to the fact that the signal of one satellite will serve as interference for the signals of the other if both satellites fall within the directional pattern of the ground antenna.

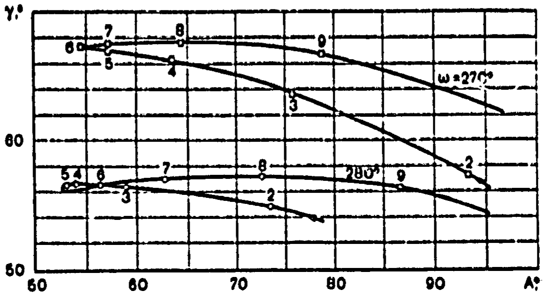


Figure 7.7. Visible motion trajectories of a satellite for Moscow ($\phi_N = 56°$; $\lambda_N - \lambda_0 = -30°$; $i = 62.8°$; $h_p = 540$ km).

To estimate the angular separation between satellites traveling in a highly elliptical orbit, we shall make use of an inertial system of coordinates, OXYZ with the origin in the center of mass of the earth, the OX axis directed towards the ascending orbital node of the i-th satellite, the OZ axis coincident with the earth's axis of rotation, and the OY axis completing the system making it rectilinear.

In the system of coordinates under consideration, the angular spacing δ between the i and $i+1$-th satellites is defined as

$$\sigma = \arccos \frac{(x_i - x_N)(x_{i+1} - x_N) + (y_i - y_N)(y_{i+1} - y_N) + + (z_i - z_N)(z_{i+1} - z_N)}{R_i R_{i+1}} \tag{7.31}$$

where $x_{i(i+1)}$, $y_{i(i+1)}$, $z_{i(i+1)}$ are the coordinates of the setting and rising satellites of the system respectively; x_N, y_N and z_N are the coordinates of the ground station;

$$R_{i,i+1} = \sqrt{(x_{i(i+1)} - x_N)^2 + (y_{i(i+1)} - y_N)^2 + (z_{i(i+1)} - z_N)^2}. \tag{7.32}$$

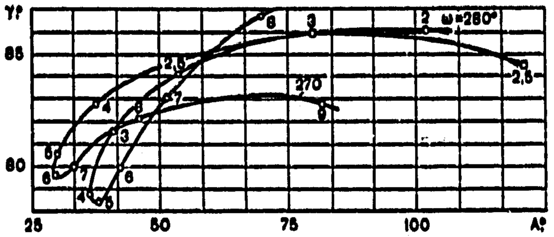


Figure 7.8. The visible travel trajectories of a satellite for Novosibirsk.

($\phi_N = 55°$; $\lambda_N - \lambda_{\text{э}} = 15°$; $i = 62.8°$; $h_p = 540$ km).

The coordinates x_N, y_N and z_N can be determined from the following formulas with a precision sufficient for this problem:

$$\left.\begin{aligned} & x_N = R\cos\varphi_N\cos\tilde{\lambda}_N;\ y_N = R\cos\varphi_N\sin\tilde{\lambda}_N;\\ & z_N = R\sin\varphi_N;\\ & \tilde{\lambda}_N = \lambda_N - \lambda_{\text{э}i} + \omega_3(t_i - \Delta t_{\text{э}i}), \end{aligned}\right\} \qquad (7.33)$$

where $\lambda_{\text{э}i}$ is the Greenwich longitude of the ascending orbital node of the i-th satellite; t_i is the travel time of the i-th satellite from orbital perigee; $\Delta t_{\text{э}i}$ is the travel time from orbital perigee to the equator;

$$\begin{aligned} & \Delta t_{\text{э}i} = \frac{T_0}{2\pi}(E_{\text{э}i} - e\sin E_{\text{э}i});\\ & E_{\text{э}i} = 2\,\mathrm{arctg}\left[\frac{\sqrt{1-e_i}}{\sqrt{1+e_i}}\,\mathrm{tg}\,\frac{2\pi-\omega_i}{2}\right]. \end{aligned} \qquad (7.34)$$

The coordinates of the i-th satellite, in accordance with (1.41) and (1.43), can be determined from the relationships:

$$\left.\begin{aligned} x_i &= a[(\cos E_i - e_i)\cos\omega_i -\\ &- \sqrt{1-e_i^2}\sin E_i\sin\omega_i];\\ y_i &= a[(\cos E_i - e_i)\sin\omega_i +\\ &+ \sqrt{1-e_i^2}\sin E_i\cos\omega_i]\cos i_i;\\ z_i &= a[(\cos E_i - e_i)\sin\omega_i +\\ &+ \sqrt{1-e_i^2}\sin E_i\cos\omega_i]\sin i_i. \end{aligned}\right| \qquad (7.35)$$

The following relationships can be employed to determine the coordinates of the (i + 1)-th satellite in the OXYZ system of coordinates:

$$\left.\begin{aligned} & x_{i+1} = x'_{i+1}\cos\Delta\Omega_{i+1} + y'_{i+1}\sin\Delta\Omega_{i+1};\\ & y_{i+1} = -x'_{i+1}\sin\Delta\Omega_{i+1} + y'_{i+1}\cos\Delta\Omega_{i+1};\\ & z_{i+1} = z'_{i+1}, \end{aligned}\right\} \qquad (7.36)$$

where $\Delta\Omega_{i+1}$ is the angle between the ascending nodes of the orbits of the i and (i + 1)-th satellites; x'_{i+1}, y'_{i+1} and z'_{i+1} are the coordinates determined from the expressions:

$$\left.\begin{aligned}
x'_{i+1} &= a[(\cos E_{i+1} - e_{i+1})\cos\omega_{i+1} - \\
&- \sqrt{1 - e^2_{i+1}}\sin E_{i+1}\sin\omega_{i+1}];\\
y'_{i+1} &= a[(\cos E_{i+1} - e_{i+1})\sin\omega_{i+1} + \\
&+ \sqrt{1 - e^2_{i+1}}\sin E_{i+1}\cos\omega_{i+1}]\cos i_{i+1};\\
z'_{i+1} &= a[(\cos E_{i+1} - e_{i+1})\sin\omega_{i+1} + \\
&+ \sqrt{1 - e^2_{i+1}}\sin E_{i+1}\cos\omega_{i+1}]\sin i_{i+1}.
\end{aligned}\right\} \tag{7.37}$$

Since the coordinates of the i and the (i + 1)-th satellites in expression (7.31) should apply to the same point in time, the value of E_{i+1} in (7.37), corresponding to E_i from (7.35), must be determined from Kepler's equation in the form:

$$E_{i+1} - e_{+1}\sin E_{i+1} = \sqrt{\frac{a^3_i}{a^3_{i+1}}}(E_i - e_i\sin E_i) - $$

$$-\sqrt{\frac{\mu}{a^3_{i+1}}}\,\frac{\Delta\Omega_{i+1}}{\omega_3},$$

причем where

$$\sqrt{\frac{a^3_i}{\mu}}(E_i - e_i\sin E_i) \geqslant \frac{\Delta\Omega_{i+1}}{\omega_3}. \tag{7.38}$$

By using the resulting expressions (7.31)-(7.38), one can determine the angle δ for a particular ground communications station as a function of the eccentric anomoly of the i-th satellite. The calculations should be performed beginning with the values of E_{i+1} which correspond to the start of the communications session through the (i + 1)-th satellite. In this case, it is necessary to check the conditions for the location of the point being considered in the radio visibility zone of both satellites, where these conditions can be written in the following form in terms of the coordinates of the satellites

$$\left.\begin{aligned}
&\frac{x_N(x_i - x_N) + y_N(y_i - y_N) + z_N(z_i - z_N)}{RR_i} \geqslant \sin\gamma_0;\\
&\frac{x_N(x_{i+1} - x_N) + y_N(y_{i+1} - y_N) + z_N(z_{i+1} - z_N)}{RR_{i+1}} \geqslant \sin\gamma_0.
\end{aligned}\right\} \tag{7.39}$$

To take into account the displacement of the routes with respect to longitude, $\Delta\lambda_3$, when determining the angle σ it is necessary to introduce the term $\Delta\lambda_3/\omega_3$ with a sign corresponding to the decrease in the angle σ for the station being considered into the right side of equation (7.38). The calculation of the angle σ from (7.31) with a particular step with respect to E_i permits the determination of its minimal value as a function of $\Delta\Omega_{i+1}$ and the orbital parameters. Thus, the minimal value of the angle σ is shown in Figure 7.9 for a ground station located in the region of Moscow as a function of the altitude of the orbital perigee and the angular separation of perigee from the node for the case of $\Delta\Omega_{i+1} = 45°$. The curve was obtained using expressions (7.31)-(7.38) for a six hour communications session where the permissible displacement of the path is $\Delta\lambda_{з} = \pm 5°$.

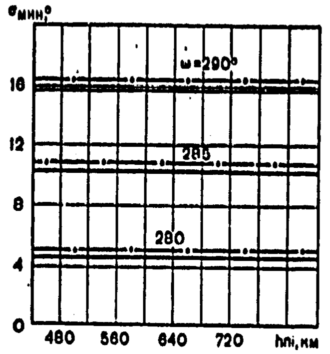


Figure 7.9. The angular separation between satellites as a function of the perigee altitude:

—— $h_{p\ i+1} = 480$ km;

—·— $h_{p\ i+1} = 800$ km.

As can be seen from Figure 7.9, the angle σ_{min} is weakly dependent on the orbital perigee altitude of both the i-th (setting) and the (i + 1)-th (rising) satellites. Within a precision of 30', one can consider the angle σ_{min} for the range of altitudes indicated in Figure 7.9 to be independent of the altitude of the perigee of the orbit.

A considerable influence is exerted on the size of the angle σ_{min} by the argument of the orbital perigee of both the setting and the rising satellites. The nature of the change in the angle σ_{min} is illustrated by Figure 7.10, from which it can be seen that the angle σ_{min} is a linear function of the arguments of the perigee of the setting (i-th) satellite.

Relationships similar to those shown in Figure 7.10 make it possible to plot lines of equal angles for σ_{min} in coordinates of the argument of the perigee of the rising satellite (ω_{i+1}) and the argument of the perigee of the setting satellite (ω_i). Such lines of equal angles of σ_{min} are shown in Figure 7.11 by way of example for $\Delta\Omega_{i+1} = 45°$ and $\Delta\Omega_{i+1} = 90°$ where the satellites operate in the main orbital revolution for the Moscow region.

Using lines of equal angles for σ_{min}, values of the perigee arguments can be chosen which assure an angle σ_{min} no smaller than a specified value for a particular point. Thus, for a point located in the Moscow region, an angular separation of no less than 5° between the satellites following each other is assured when $\Delta\Omega_{i+1} = 90°$, if orbits with two values of the perigee arguments are employed in the system, for example, 280 and 287°.

Because of the fact that to service the northern hemisphere, stationary satellites can be employed along with satellites in highly elliptical orbits, there is unquestionable interest in determining the angular separation between these types of satellites. It follows from the analysis of the flight path of a satellite in a highly elliptical orbit (see, for example, Figure 2.6), that the minimum value of the angle between the direction to a

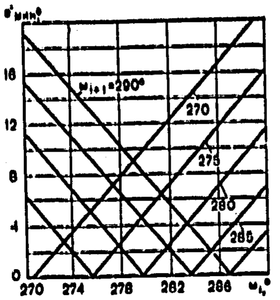


Figure 7.10. σ_{min} as a function of the argument of the perigee of a rising satellite in the main orbital revolution for the region of Moscow ($\Delta\Omega$ = 45°; h_p = 640 km).

stationary satellite and a satellite in a highly elliptical orbit from a ground station will occur at the start and the conclusion of a communications session through the satellite in the elliptical orbit. In this case, the size of the angle between the satellites depends substantially on the location of the fround station. The case where the stationary atellite, the satellite in the elliptical orbit and the ground station are positioned in the same meridian plane with the maximum distance between the point and the equatorial plane, i.e., at the boundary of the radio visibility zone of the stationary satellite will correspond to the minimal value of the angle (Figure 7.12).

The minimum angle made between the ground station and the direction to the stationary satellite and the satellite in a highly elliptical orbit can be determined taking what has been said above into account as follows. For the point in time under consideration for the start or conclusion of a communications session through the satellite in the highly elliptical orbit, the true anomaly θ can be determined using (1.15) and (1.16), and this means, also the value of the argument of the satellite latitude u. The corresponding values of the orbital radius and the geocentric latitude of the satellite are:

$$r = \frac{a(1-e^2)}{1+e\cos\vartheta}; \quad \varphi = \arcsin(\sin u \sin i). \qquad (7.40)$$

We shall use a sphere of radius R as a model of the earth. In this case, the geocentric latitude of the earth station coincides with the geodesic latitude. Taking into account the fact that the stationary satellite, the satellite in the highly elliptical orbit and the ground station are arranged in the same meridian plane, expressions can be written for the angular coefficients of the direction of the ground station to the satellites:

$$K_1 = \frac{r\sin\varphi - R\sin\varphi_N}{r\cos\varphi - R\cos\varphi_N}; \quad K_2 = -\frac{R\sin\varphi_N}{r_0 - R\cos\varphi_N}; \qquad (7.41)$$

where r_0 is the radius of the stationary orbit.

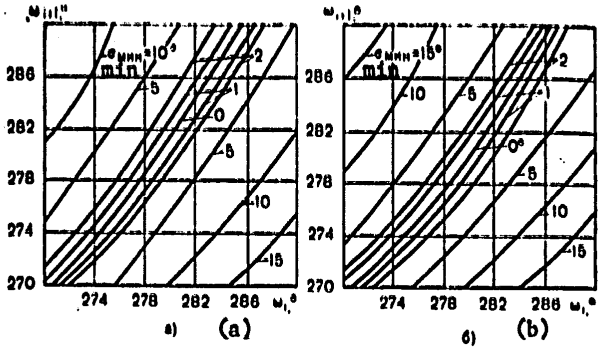


Figure 7.11. Lines of equal values of σ_{min} in the main orbital revolution for a point in the region of Moscow:

a) ΔΩ = 45°;
b) ΔΩ = 90°.

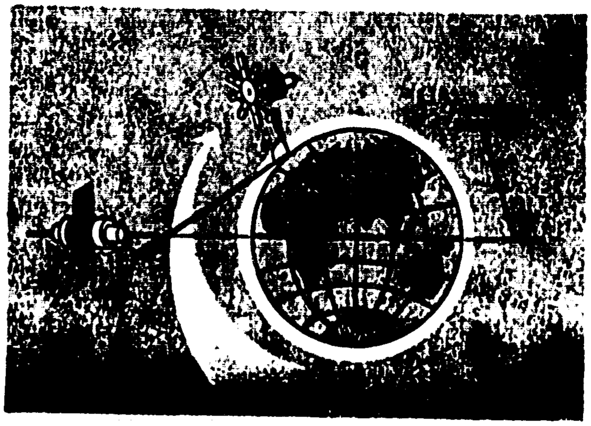


Figure 7.12. On the determination of the mutual visibility between satellites in highly elliptical and stationary orbits

Key: 1. Equatorial plane.

At the boundary of the radio visibility zone of the stationary satellite, the geodesic latitude of the ground station (given the condition of a spherical earth) is:

$$\varphi_N = \arccos \frac{R}{r_0}. \qquad (7.42)$$

Then the value of the angle between the directions to the satellites, taking (7.36) into account, can be determined from the expression:

$$\sigma = \operatorname{arctg} \frac{r r_0 \sin\varphi - R r \sin(\varphi - \varphi_N) - r_0 R \sin\varphi_N}{R^2 + r r_0 \cos\varphi - R r \cos(\varphi - \varphi_N) - r_0 R \cos\varphi_N}. \qquad (7.43)$$

The results of an analysis of the angular separation between the directions to the satellites, based on (7.40)-(7.43), are given in Table 7.4 where the angular spacing between the satellites is presented as a function of the start and conclusion times for communications through the satellite in the elliptical orbit and as a function of the angular separation of perigee from the node.

Table 7.4

(1) Значение аргумента перигея, °	(2) Время начала сеанса связи (от перигея)				(3) Время конца сеанса связи (от перигея)			
	1.5	2.0	2.5	3.0	9.0	9.5	10.0	10.5
270	36°00′	46°15′	53°20′	58°10′	58°10′	53°20′	46°15′	36°00′
280	45°20′	54°45′	60°35′	64°35′	49°50′	43°50′	36°05′	26°00′
285	49°50′	58°00′	63°40′	66°20′	45°30′	39°20′	31°25′	20°30′
290	53°30′	61°40′	65°45′	67°30′	41°05′	34°40′	26°45′	15°55′

Key: 1. Value of the perigee argument, °;
2. Time of the start of a communications session (from perigee);
3. Time of the end of a communications session (from perigee).

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PHYSICS

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LASER SPECTROSCOPY IN NUCLEAR PHYSICS

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/Article by Doctor of Physical and Mathematical Sciences V.S. Letokhov]

/Text/ Considerable progress has been achieved during the past several years in development of methods of coherent light generation and frequency control. It has become possible to change to systematic investigation of rather fine effects of the resonance interaction of coherent light with atoms and molecules. This field of research is usually called laser spectroscopy. The developed methods of laser spectroscopy are already beginning to be applied in many fields of science and technology; in quantum metrology (quantum frequency and length standards), in chemistry (laser separation of isotopes and production of pure materials), in analytical technology (laser spectrometers and detectors of small -- trace -- numbers of atoms and molecules), in geophysics (monitoring polluting impurities in the atmosphere and the search for fuels by accompanying gases), in biology (investigation of photosynthesis and the molecular mechanism of vision) and so on. The field of nuclear physics research in which methods of laser spectroscopy also open up new experimental opportunities is considered in the given article.

As is known, many characteristics of the nucleus -- the number of protons and neutrons, spin, the quadrupole moment of the nucleus and the related shape, mean radius and excitation of the nucleus and also its velocity and orientation (Table) -- are clearly manifested in the fine structural details of the outer electron shell of an atom, that is, in the optical spectrum of the atom.

It is this that permits the use of laser spectroscopy methods in nuclear physics investigations in which operations with nuclei having the required characteristics are conducted by the effect of coherent light on the electron cloud surrounding the nucleus. Of course, such methods of effect of laser emission on atoms which would permit selective excitation and ionization of each atom with a nucleus of selected variety, production of an observed signal from each individual atom, which would permit one to extract each selected atom from the mixture and so on must be developed for this. The progress achieved during the past few years in methods of laser spectroscopy made it possible to solve the ennumerated problems and to open up new prospects in nuclear physics research.

Manifestation of Nuclear Characteristics in the Optical Spectrum of the Atom

Characteristics of Nucleus	Manifestation of Characteristics of Nucleus in Optical Spectrum of the Atom
Type of nucleus (charge Z)	Wave length of absorption lines
Isotope composition (no. of neutrons)	Isotope shift
Spin and magnetic moment	Superfine structure (STS)
Quadrupole moment	Superfine structure
Shape and mean radius	Superfine structure
Excitation	Superfine structure
Orientation	Population of magnetic sublevels
Velocity	Doppler shift of absorption lines

Laser Detection of Single Atoms

Considerable attention has recently been devoted to developing methods of laser detection of supersmall, or as they say, trace amounts of material.[1] The essentially detectable limit is one atom since it still carries complete spectral information about its own structure. Therefore, one of the main purposes of laser spectroscopy is to develop methods of detecting single atoms. The method of laser excitation of resonance fluorescence, which makes it possible to find the maximum number of photons scattered by one atom, and the method of selective step ionization of atoms by laser emission which essentially permits transformation of each atom into an ion, are most promising. Both methods were recently implemented successfully[2] at the Institute of Spectroscopy of the USSR Academy of Sciences.

The problem of detecting single atoms can be divided into three successive stages: (1) accumulation of the element and production of free atoms; (2) transport of atoms to the detection zone; (3) detection of the atom. Solution of all these problems is very important for using methods of laser spectroscopy in nuclear physics investigations. Success has not been achieved in working out the third problem: a selective signal (in the form of photons or ions) significantly exceeding the noise level can be produced from a single atom interacting resonantly with one or several laser beams so that the fact of transit of the atom through the laser light field can be reliably established. Therefore, let us initially consider methods of detecting single atoms and then let us discuss the first and second problems with respect to nuclear physics investigations.

The fluorescence method. The characteristic feature of the method of resonance fluorescence is that the same atom can interact several times with the laser emission, reemitting photons of the same frequency as the exciting photons in all directions. If the laser emission intensity exceeds the resonance transition saturation intensity, the populations of the ground and excited levels become identical. In this case the atom reemits $N_{max} \approx T/2\tau_{pont}$ photons where τ_{pont} is the time of spontaneous decay of the excited state to the ground state, during time T of intersection of the light beam.

As an example, let us estimate the maximum number of photons spontaneously reemitted by a sodium atom. The mean velocity of the thermal motion of $Na(v_t)$ atoms at 50°C comprises $5 \cdot 10^4$ cm/s. The decay time of the first excited state of Na τ_{pont} is $1.6 \cdot 10^{-8}$ s. Therefore, a sodium atom is capable of reemitting $N_{max} = 250$ photons on a path of $h = 0.4$ cm(corresponding to experimental conditions). One can gather $N_{det} = 20$ photons on the cathode of a photomultiplier with a value of the solid angle of the scattered emission sampling (Ω) of 1 sr. The best FEU /photomultiplier/ have quantum efficiency of $\eta = 0.1$-0.2 at wavelength of $\lambda = 589$ 1m. Thus, one can expect the appearance of 2-4 photoelectrons from the FEU photocathode from each atom passing through the laser beam.

This experiment was carried out at the Institute of Spectroscopy of the USSR Academy of Sciences by using a CW dye laser whose frequency was tuned to the D2 resonance line of a Na atom. The fluorescence signal was recorded by two FEU and a two-channel recording system operating in the coincident mode was used to separate it. With laser emission intensity providing absorption saturation, the atom reemitted a number of photons sufficient for at least one single-electron pulse to be formed at the output of each FEU during the time the atom was located in the beam. During this time, the appearance of pulses at the FEU output was regarded as a coincident event. This recording scheme permitted, first, a considerable reduction of the phonon effect and, second, made it possible to establish the effect of intersection of the laser beam by the atom. The ratio of the number of phonon photons impinging on the FEU cathode to the number of resonance-scattered photons of laser emission contained in the cuvette comprised 10^{-14} for a specially designed cuvette in which the atom beam and laser beam intersected. A total of 10^{-2} phonon photons impinged on the FEU cathode during the transit of the atom through the laser beam under the experimental conditions.

The dependence of the Na atomic flux, measured in this experiment, through the recording range on the beam source temperature is presented in Figure 1. The minimum signal is detected at furnace temperature of 43°C. In this case a flux of 10 atoms per second is detected, which corresponds to the mean atomic density of 10^{-4} in the recording range. This maximum detection was related to the inevitable effect of phonon emission participating in formation of the pulses in the coincidence circuit.

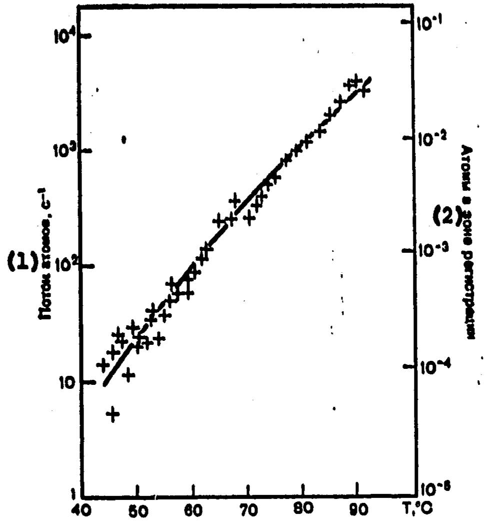

Figure 1. Experimental Dependence of Sodium Atom Flux Through Laser Beam on Furnace Temperature Measured by the CW Laser Fluorescence Excitation Method.

Key:

1. Atom flux s^{-1}
2. Atoms in recording zone

The fluorescence method of detecting single atoms is based on cyclic stimulated excitation and spontaneous reemission of photons. By using existing lasers, this method can be realized for the time being only for alkali and alkali earth elements. The cyclicity of the process is easily interrupted for most the remaining, especially complex atoms having metastable states near the ground state, since only the atom drops to the metastable state. In these cases the maximum detection is increased to 10^2-10^4 atoms, which incidentally is quite acceptable for some problems of laser physics discussed below. However, the photoionization method is more efficient and universal.

The photoionization method. This approach to detection of single atoms is based on the idea of their selective step photoionization, proposed by the author in 1969 both for isotope separation and for detection of atoms. If detection is carried out in a vacuum (the most interesting case from the viewpoint of maximum spectral resolution), laser emission pulses with frequency of approximately 50 kHz (at velocity of $5 \cdot 10^4$ cm/s and interaction path of 1 cm) must be transmitted for ionization of each atom that has entered the laser beams. Effective ionization of most atoms can be achieved only if the atom is ionized through the overlying (Ridberg) states with the mean output of retuned laser emission accessible under laboratory conditions (on the order of 1 W). This method of selective ionization was proposed and investigated at the Institute of Spectroscopy of the USSR Academy of Sciences.[3]

In these investigations, the non-resonance process of photoionization of an atom in transition from the intermediate state to the continuum is replaced by a process of resonance excitation of an atom from the same state to the overlying state near the ionization boundary with subsequent ionization by a pulse of the electric field. The effectiveness of ionization is close to unity in this process. Since excitation at all the subsequent states is resonance, comparatively low energy density of laser pulses (10^{-4} to 10^{-6} J/cm^2), completely achievable by means of existing dye lasers, is required for saturation of all transitions.

For illustration, let us present the latest results on detection of single ytterbium atoms.[4] A simplified diagram of the energy levels of an ytterbium atom and the typical diagram of the quantum transitions used in excitation of the Ridberg state are presented in Figure 2. A three-step excitation scheme using three pulsed dye lasers excited by a single pulsed nitrogen laser was used. By readjusting the emission wavelength of the third laser in the range of 5,950-5,770 Å, one can transfer the Yb atoms to P-states with the main quantum number of n = 14-20. The atoms are then easily ionized by an electric field pulse with intensity of 10-15 kV/cm.

The configuration of the atomic beam, laser beams and the direction of motion of the formed ions is shown in Figure 3. The laser beams intersected the atomic beam between two electrodes to which an electric field pulse was fed. The ions resulting from selective ionization were extracted through a slit in one of the electrodes and were recorded a second time by an electron multiplier tube. The experimental conditions made it possible to extract practially all the ions from the interelectrode gap.

When the laser pulse energy exceeded the saturation energy of each transition, the atoms were uniformly distributed along the ground, intermediate and final states according to their statistical weight. For example, 5/12 of all atoms located in the excitation zone converted to the final $17^3P^0_2$-state. Recording of single atoms with quantum efficiency of approximately 50 percent was achieved under these very conditions.

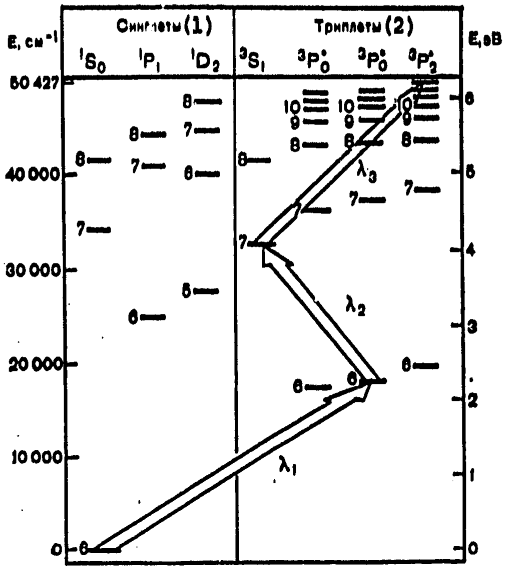

Figure 2. Diagram of Ytterbium Atom Levels and Quantum Transitions Used for Three-Step Excitation of an Atom for Ridberg States and Subsequent Ionization of it by an Electric Field Pulse: $\lambda_1 = 555.6$ lm; $\lambda_2 = 680$ nm; $\lambda_3 = 577$-595 nm

Key:

1. Singlets
2. Triplets

The experimental dependence of the ytterbium ion output per pulse on the furnace temperature is presented in Figure 4, a. The calculated dependence of the number of Yb atoms in the recording zone (dashed curve) is also presented in this figure. The difference in the course of the experimental from the calculated curve at temperatures below 250°C is apparently related to the fact that the atomic pair in the furnace was unsaturated under the experimental conditions. The strong instability of the ion signal was caused by fluctuations of the number of atoms in the excitation zone with the lowest possible atomic beam intensities. Actually, the probability of two atoms impinging in the excitation zone simultaneously will be much less than the probability of one atom impinging in this zone under these conditions. In this case the recording system will respond in most cases upon the appearance of only a single atom and the probability of recording k-ions P(k) will be determined by Poisson distribution. This is clearly confirmed experimentally. The values of P(k) for ytterbium atoms at two different values of the average number of atoms $\bar{N}$ in the excitation zone are presented in Figure 4, b and c. The Poisson distributions (solid lines), calculated for the same values of $\bar{K}$, are presented for comparison.

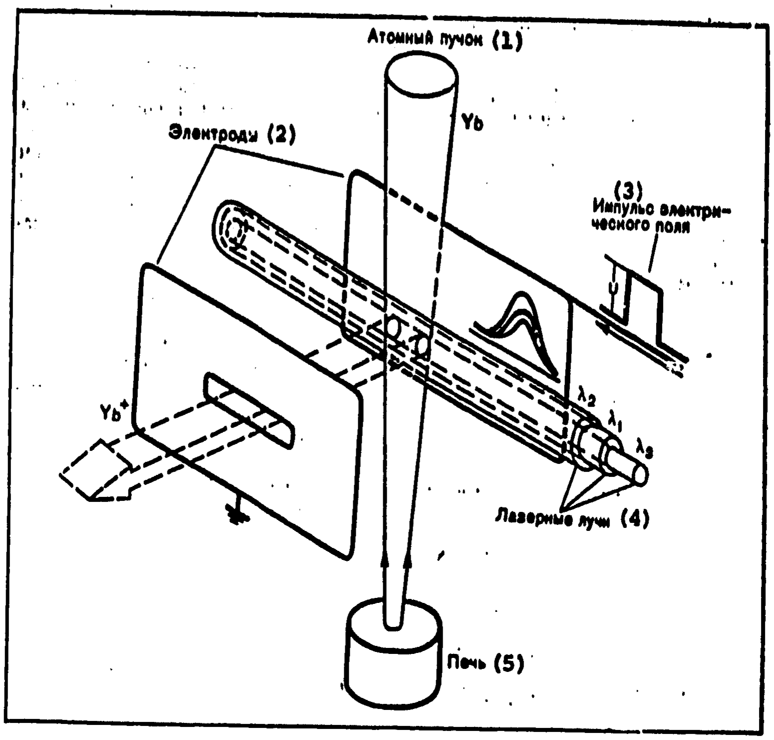

Figure 3. Detecting Cuvette of Experimental Installation for Photoionization Detection of Single Atoms Through Ridberg States (the Configuration of the Atom Beam Through the Laser Beams and the Beam of the Formed Ions in the Region of Interaction of Atoms with the Laser Beams and the Electric Field Pulse is given)

Key:

1. Atomic beam
2. Electrode
3. Electric field pulse
4. Laser beams
5. Furnace

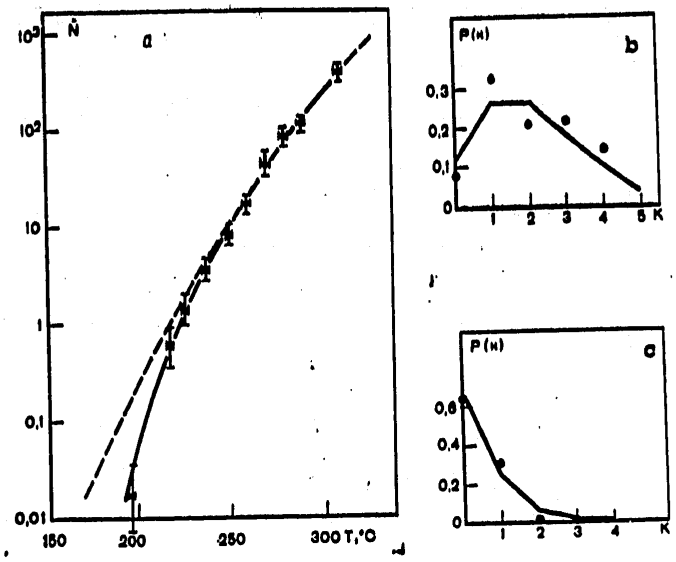

Figure 4. Experimental Data which Demonstrate Photoionization Detection of Single Yb Atoms: a -- dependence of number of atoms in the observation zone on furnace temperatures; b -- distribution of number of ion counts during 5 seconds of observation with average number of atoms in the observation zone of $\bar{N} = 0.04$; c -- the same during 30 seconds of observation at $\bar{N} = 0.003$

Investigating Nuclei Accessible in Small Quantitites by Laser Spectroscopy Methods

The high sensitivity and resolution of laser spectroscopy methods permit investigation of the characteristics of nuclei accessible only in very small quantities. Successful experiments on investigation of radioactive nulcei far from the stability boundary have been conducted in a number of foreign laboratories (Switzerland, West Germany and France). Almost all the experiments were carried out by the simplest method of fluorescence excitation of atoms using the emission of a retuned dye laser. Specifically, an installation is operating at CERN for investigation of the superfine structure of the optical lines of atoms with short-lived nuclei on a mass separator operating on a single line with a synchrocyclotron rated at 600 MeV (the ISOLDE installation).

A proton beam irradiates a target from which unstable nuclei formed in the volume are evaporated after diffusion. The flux of evaporated atoms enters an ionizer and then the mass separator at whose output fluxes of monoisotope atoms with intensity of 10^7-10^{11} ions per second are achieved. The flux of mass-separated ions is either collected in the source of radioactive atoms if the nuclear decay time is sufficiently high (hours or days) or is neutralized directly during the charge-exchange process if the nuclear decay time is short (seconds or minutes). The atoms in the form of an atomic beam or in a gas may then be completely investigated by laser spectroscopy methods.

Let us present as an example the results of investigating short-lived nuclei produced on the line of the ISOLDE mass separator by laser spectroscopy methods.[5] Even neutron-deficient unstable isotopes of $Hg^{182-190}$ were investigated on this installation. The ion flux intensity of these isotopes with lifetimes from 1 to 60 minutes comprises 10^7-10^9 ions per second. The superfine structure (STS) of the 2,537 Å line of mercury, assuming a total of 10^8 atoms of the mercury isotope, can be measured within 1-2 minutes during fluorescence excitation using pulse dye laser emission whose second emission harmonic is retuned to the region of λ = 2,537 Å. The isotope shift of the optical transition of one isotope A with respect to another B is measured from STS data:

$$\Delta\nu_B^A = \frac{2}{3}\pi Ze^2\Delta|\psi(0)|^2\delta\langle r^2\rangle,$$

where $\delta\langle r^2\rangle$ is the variation of the mean square of the radius of the nucleus of isotope A with respect to B and $\Delta|\psi(0)|^2$ is variation of the electron density on the nucleus in the observed electron optical transition. The mean square of the atomic charge radius is calculated from measurements of the isotope shifts. The dependence $\langle r^2\rangle$ of neutron-deficient mercury nuclei on the number of neutrons, obtained by West German scientists on the ISOLDE installation at CERN, is shown in Figure 5. A sharp jump of the mean square of the atomic radius was detected during transition from the Hg^{186} nucleus to the Hg^{185} nucleus. This jump is now interpreted as sharp variation of the shape of the nucleus (an increase of asphericity) with a subsequent decrease of the number of neutrons.

These types of investigations of nuclei far from stability can now be conducted by using laser spectroscopy methods for almost all elements of the periodic table and the sensitivity and resolution of the measurements can be brought up to maximum values. Specifically, if one turns to excitation of fluorescence by a CW laser or to selective step photoionization by pulsed lasers, one can work with maximum sensitivity corresponding to a single atom in the resolved spectral range. A total of 10^3-10^4 atoms is required for accurate determination of STS and for measurement of the isotope shift. One can detect very small isotope shifts by using the developed methods of nonlinear spectroscopy,[6] which permit measurements inside the Doppler circuit.

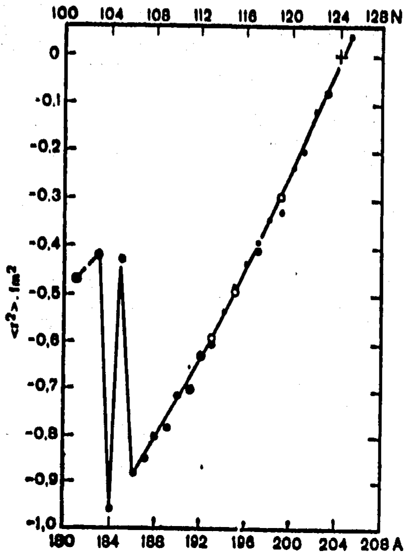

Figure 5. Variations of Charge Radii of Mercury Isotopes with Respect to Hg^{204} Isotope Measured by the Laser Spectroscopy Method

The least nuclear decay time during which the STS spectrum can be measured is determined by the diffusion time of radioactive nuclei from the target to the surface and their arrival at the mass separator input rather than by the measurement process itself. The high sensitivity of laser methods permits a reduction of nuclear concentration due to radioactive decay by a factor of 10^3-10^5. Moreover, by using special porous targets, one will apparently be able to investigate the characteristics of nuclei with decay time shorter than 1 second down to 10^{-2} to 10^{-3}s.

We note that mass separation of radioactive nuclei can be rejected and ion flux with nuclei of the selected isotope can be directly achieved by the selective step photoionization method as is usually done in experiments on laser separation of isotopes. Measuring the ion output during retuning of the exciting laser emission frequency immediately provides data on the STS spectrum with simultaneous separation of the excited atoms. In this case the mass separator is required only to determine the mass (if it is unknown) of selectively ionized atoms.

Rapid measurement of the superfine structure and of the isotope shift by laser spectroscopy methods is essentially direct measurement of the dimensions of short-lived nuclei. This is the principle characterstic of laser spectrosocpy methods since, unlike methods of investigation existing in nuclear physics, it is unrelated to any specific properties and channels of radioactive isotope decay. This is possibly more significant when searching for nuclei with new, unexpected properties. Specifically, the laser approach is the most suitable for direct proof of the existense of spontaneously fissionable isomers of transuranium nuclei. For example, it is expected that a spontaneously fissionable Am^{242m} nucleus will live for approximately 10^{-2} s. The isomerism of the form can be proved by directly measuring the mean square of the nuclear charge radius using a laser spectrometer of one of the types described above which operates to the line with the accelerator. An output of approximately 10^3-10^4 of these nuclei from the accelerator target is required to measure the STS and the isotope shift by the photoionization laser method.

Another important trend is the search for so-called superdense nuclei, whose existence was predicted by Academician A. B. Migdal.[7] Experiments have been conducted up to the present on detection of superdense nuclei in natural specimens and in products of high energy particle-matter interaction. V. A. Karnaukhov recently gave a survey and analysis of these investigations.[8] The results of the search are still negative, which eliminate the existence of superdense nuclei in nature with binding energy of approximately 100 MeV per nucleon. The problem of the existence of superdense nuclei with lower binding energies has not actually been investigated. The search is only beginning on accelerators. The method of the rather "narrow" search for some specific anticipated properties of superdense nuclei was used during the conducted investigations. Therefore, it is important to utilize the laser method, free of restrictions and which permits direct measurement of nuclear dimensions. Such properties of superdense nuclei as binding energy and the properties of decay of radioactive isotopes, which are now difficult to predict, are of no significance for the laser method. The experiments described above on detection of single atoms were stimulated to a specific degree by the prospect of this type of fundamental research.

Simple estimates made by the formula presented above showed that the strong difference in the dimensions of normal and superdense nuclei lead to an isomeric shift of the electron transition frequency by a significant value (on the order of $5\cdot10^{-3}$ eV $\simeq 40$ cm^{-1}). This shift exceeds almost 100-fold the ordinary isotope shift and almost 1,000-fold the actual width of the optical spectral lines. This potentially guarantees high relative sensitivity of detecting single atoms with superdense nucleus far on the limb of the spectral line of ordinary atoms. The relative sensitivity comprises 10^{-11} to 10^{-12} for the fluorescence laser method of detecting an atom with a superdense nucleus, while the relative sensitivity may actually be brought up to values of 10^{-20} for the method of selective three-step photoionization (where the frequency shift is manifested on at least two successive steps of resonance excitation).

Apparently, the search for superdense nuclei can be conducted sequentially in two stages. The existence of very small numbers of stable superdense nuclei can be investigated initially. According to π-condensation theory, radioactive superdense nuclei should be considerably shorter-lived than ordinary nuclei. As a result of β decay they should be transformed to stable superdense nuclei of a specific element by which the specimen can be enriched for investigation on a laser spectrometer unconnected to an accelerator. In this case the method of multistep selective photoionization is preferable for realizing the highest maximum relative sensitivity. Of course, one must utilize pulsed dye lasers with very high pulse recurrence frequency (10-50 kHz). This is necessary to irradiate all the atoms in the beam which intersect the laser beam.

This problem also exists in installations for laser separation of isotopes where high pulse recurrence frequency is also required for complete extractions of the whole isotope with single evaporation of the material. The problem can be solved by pumping dye lasers by a pulsed-gas discharge copper-vapor laser which can operate with pulse recurrence frequency up to 50 kHz at efficiency on the order of several percent.

A laser spectrometer can be developed during the second stage directly on the line of the heavy ion acceleration complex, which is regarded as more suitable for creation of superdense nuclei.

All the described methods of laser spectroscopy are quite suitable for detection and identification of new transuranium and superheavy elements.

Possibililty of Laser Control of Proton Beam Parameters

New ideas have recently appeared on the possibility of controlling some important parameters (polarization, energy, monochromaticity) of charged particle beams (specifically, protons) by using laser emission. These ideas are based on recently developed methods of nonlinear laser spectroscopy without Doppler breadth[9] and selective multistep ionization of atoms by using laser emission with retuned frequency. Figure 6 represents a simplified illustration of the possible methods of controlling charged particle beam parameters.

First, hydrogen atoms with specific projection of velocity onto the selected direction can be excited by monochromatic laser emission (see Figure 6,a). With motion of hydrogen atoms at relativistic velocity toward the laser beam, this excitation can be accomplished on the transition $L_{\alpha}(\lambda_0 = 1,215 \text{ Å})$ even without laser emission in the vacuum ultraviolet region. Using the recently well-developed method of multistep photoionization of atoms through the overlying states, each excited hydrogen atom can be ionized with quantum yield of approximately one, that is, a proton beam with precisely defined velocity or energy in a very narrow range can finally be produced. This is the essence of the idea of laser monochromatization of a proton beam.

Of course, the initial relativistic proton beam must be converted to hydrogen atoms to realize this approach. At the modern level of technology of retuned lasers, this method provides a resolution of $10 \cdot 10^5$ on existing accelerators. If the proton beam spectrum is constricted, its intensity drops proportionally since the laser monochromator is a unique realization of the "Maxwell domain" which selects hydrogen atoms with specific velocity. However, reduction of beam intensity during monochromatization does not lead to a loss of the last, untouched part of the beam, which can be utilized in an accelerator by the ordinary method. We note that any narrow energy interval inside the spectral width of accelerated protons (after they are converted to hydrogen items) can be separated by retuning the laser emission wavelength λ_1 on the resonance 1S-2P-transition. Precise measurement of the wavelength λ_1 at the same time provides absolute measurement of the energy of monochromatized protons with accuracy not less than 10^{-5}.

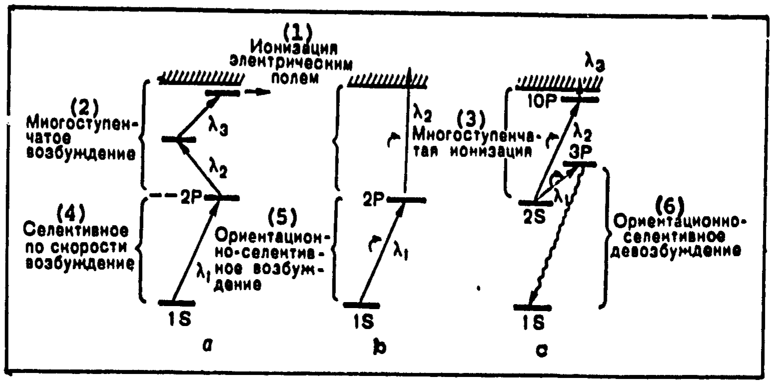

Figure 6. Simplified Diagram of Controlling Proton Beam Velocity (a) and Polarization (b & c) Based on Multistep Selective Photoionization of Hydrogen Atoms

Key:

1. Ionization by electric field
2. Multistep excitation
3. Multistep ionization
4. Selective excitation by velocity
5. Orientation-selective excitation
6. Orientation-selective deexcitation

Second, atoms on a specific transition of superfine structure can be excited by circularly polarized laser emission and then the selectively excited items can them be photoionized (See Figure 6,b). The interaction of the electron moment with the nuclear spin leads to the fact that moment of the absorbed photon is distributed between the electron and nucleus and as a result preferred orientation of the nuclei occurs in the ensemble of ions. The most important case of proton polarization by this scheme is essentially difficult to realize due to the absence of laser sources at $\lambda (L_\alpha) = 1{,}215$ Å with the required parameters (proton polarization should be carried out at the accelerator input when the hydrogen atoms have nonrelativistic velocity). Moreover, atomic beams with low angular aperture (less than 1°) must be used for selective optical excitation by STS components in order that the Doppler breadth of the absorption line be much less than the distance between the selected STS components. Therefore, the main potential advantage of the laser method -- the possibility of producing intensive wide-aperture polarized proton beams at the accelerator input -- cannot be realized by this scheme.

Another, more realistic scheme, based on ionization of hydrogen atoms from the metastable 2S-state, was recently proposed (see Figure 6,c). In this scheme the nuclei are initially oriented by selective deexcitation of atoms from several STS sublevels using laser emission on the H_α line and multistep ionization of the oriented metastable atoms is then carried out.

The proposed method has essential advantages compared to existing methods. The most important of them are the maximum high degree of proton polarization (practially 100 percent), the significant angular aperture of the atomic beam used (up to 10 percent), reduction of the dimensions of the polarization zone to several centimeters and the possibility of rapid variation of the direction of polarization. At the modern level of the technology of retuned lasers, this method permits production of approximately 25 percent of polarized protons from the total number of atoms in the metastable $2S_{1/2}$-state. It should be emphasized that an increase of the solid angle of the atomic beam by an order of 3-4 compared to existing methods should lead to a corresponding increase of polarized proton beam intensity. Of course, all the noted characteristics are retained when producing polarized ions of other elements if selection by total (and this means nuclear) moments is carried out by using optical orientation of atoms and if ionization of the oriented atoms is accomplished through Ridberg states.

The brief survey of some possibilities of using laser spectroscopy methods in nuclear physics research shows that a new promising trend is being born on the boundary of laser and nuclear physics. Even at the existing level of technology of retuned lasers, one can first develop new highly efficient methods of detecting and measuring the parameters of the smallest possible number of nuclei directly on a single line with the accelerator and, secondly, create new methods of controlling proton beam parameters and the input (polarization) and output (monochromatization and energy measurement) of the accelerator.

FOOTNOTES

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PUBLICATIONS

SYSTEMOLOGY AND LINGUISTIC ASPECTS OF CYBERNETICS

Moscow SISTEMOLOGIYA I YAZIKOVYKH ASPEKTY KIBERNETIKI (Systemology and Linguistic Aspects of Cybernetics) in Russian 1978 signed to press 12 Apr 78 pp 2, 15-17, 368

[Annotation, author's foreword and table of contents from book by G. P. Mel'nikov, "Sovetskoye radio," 4,600 copies, 368 pages]

[Text] With increasing complexity of the problems to be solved and the technology used, the limitedness of the conceptual apparatus of cybernetics, oriented toward the development of only formal mathematical modeling, becomes more and more obvious. Presented in the book is a systemological conception with the purpose of enriching that apparatus by methods of effective analysis of the problems to be solved on the basis of consideration of distinctive features of unformalized parameters of the object to be studied or designed. The effectiveness of these methods is demonstrated in the process of analysis of the mechanisms of effective communication with a natural language in the aspect of improvement of the principles of man-machine communication.

The book is intended not only for cyberneticists but also for semiologists psychologists and linguists.

Author's Introduction

The book is a result of long work in two outwardly independent scientific areas. Firstly, in the area of the design and operation of cybernetic electronic automata to conduct experiments in nuclear physics; secondly, in the area of investigation of the grammatical structure of various natural languages (the Turkish, Bantu, Semitic, Chinese, Hungarian, etc), which with time merged with work in the area of information science and the theory of scientific and technical translation. The basis for the unification of all those investigations was the development of the methodological principles of systemology (the systems approach), which enabled the author to see the fruitfulness of using engineering concepts and experience in solving complex problems of linguistics and semiotics and to borrow methods of data processing and transmission which had formed in the grammars of various "exotic" languages to solve problems in the designing of cybernetic information automata.

A number of circumstances contributed to the formation of the described systemological conception and verification of the effectiveness of its applications. There were, above all, the benevolent attitude of the leaders of the Institute of Atomic Energy imeni I. V. Kurchatov of the USSR Academy of Sciences, especially of M. D. Millionshchikov, toward the author's work on linguistic aspects of cybernetics; close scientific contacts with the developers of the principles of machine translation, especially at MGU (Moscow State University) and MGPIIYa (Pervyy Moskovskiy gosudarstvennyy pedagogicheskiy institut inostrannykh yazykov--First Moscow State Pedagogical Institute of Foreign Languages) in the initial stages of those investigations, and constant interaction with many sections of the Institute of Eastern Studies and the Institute of Linguistics of the USSR Academy of Sciences (Moscow and Leningrad departments), participation in the work of seminars and conferences organized by them and co-authorship in work on the collective monograph "Obshcheye yazykoznaniye" (General Linguistics) under the editorship of B. A. Serebrennikov; many years of teaching the courses "Introduction to Mathematics for Linguists" and "System Typology of Languages" in the Faculty of Philology of MGU, and also active participation in measures of the Problem Group for Semiotics at MGU led by A. G. Volkov; close scientific collaboration with the Institute of Mathematics of the Siberian Department of the USSR Academy of Sciences, where conversations and discussions with scientific associates of that institute N. G. Zagoruyko, E. V. Yevreinov and especially with Yu. G. Kosarev were extremely fruitful for the author.

The author also was lucky enough to work for several years in the same collective with P. G. Kuznetsov and S. P. Nikanorov, whose profound scientific ideas, comprehensive analysis, constant readiness to help and impartial criticism of everything indecipherable and loose in the discussions contributed to the formation of the systemic views of the author.

The popularization of these views drew attention to the author's works on the part of members of the group of systems research of the Institute of History of the Natural Sciences and Technology of the USSR Academy of Sciences and, above all, on the part of V. N. Sadovskiy. Upon the initiative of the scientists of that group the author was able to acquaint not only soviet but also foreign specialists with the results of his investigations.

Contributing to success in the development of work on the linguistic aspects of cybernetics were the reports of the author presented in the House of Scientific and Technical Propaganda imeni F. E. Dzerzhinskiy at sessions of the section "Theory and practice of scientific information," led by T. V. Muranivskiy, and also annual presentations at all-union conferences organized by the Section of Theory and Practice of Scientific and Technical Translation under the Council of Scientific and Technical Societies, headed by A. L. Pumpyanskiy. One must also note the favorable conditions for scientific work presented to the author in recent years in the Computer Laboratory of the faculties of the humanities of Moscow University. Of great importance for the success of the investigations being conducted was the

benevolent attitude toward them on the part of the well-known soviet cyberneticists B. S. Fleyshman, G. N. Povarov and A. V. Napalkov, and also constant communication and discussion of successive problems with scientific associates of the laboratory Yu. I. Feodoritov and I. A. Butin. Conversations with G. G. Gribakin were very fruitful for the solution of questions of principal importance for linguistic aspects of cybernetics. The author expresses his heartfelt thanks to all the persons named.

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PUBLICATIONS

UDC 681.3.001.2

ANALYTICAL PROBABILISTIC MODELS OF ELECTRONIC COMPUTER FUNCTIONING

Moscow ANALITICHESKIYE VEROYATNOSTNYYE MODELI FUNKTSIONIROVANIYA EVM (Analytical Probabilistic Models of Electronic Computer Functioning) in Russian 1978 signed to press 18 Jul 78 pp 2, 166-168

[Annotation and table of contents from book by G. T. Artamonov and O. M. Brekhov, "Energiya," 7,000 copies, 368 pages]

[Text] Problems in the determination and use of mathematical models of electronic computer functioning in the stage of planning the structure of the machine are examined in the book. A determination of models of their functioning is presented with the use of examples of classic electronic computer structures. A formal functional model of a hypothetical contemporary electronic computer is determined, with consideration of which a mathematical model of the process of program execution in a machine, considered as a mass service system, is constructed. A number of practical models of program execution are investigated which make it possible for planners of electronic computer structures to determine analytically or by calculation the influence of various parameters of structures and programs on the capacity of the machine.

The book is intended for specialists in computer technology and also for students of senior courses in the corresponding specialties.

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Part Two. Distinctive Features of Electronic Computer Models

Part 3. Models of Processes of Problem Solution with Computers

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PUBLICATIONS

ECONOMICS AND ORGANIZATION OF DATA PROCESSING SYSTEMS

Moscow EKONOMIKO-ORGANIZATSIONNYYE OSNOVY SOZDANIYA SISTEM OBRABOTKI DANNYKH (Economic-Organizational Principles of Developing Data Processing Systems) in Russian 1978 signed to press 8 Apr 78 pp 2, 160

[Annotation and table of contents from book by I. S. Zinger, A. A. Modin, and M. F. Korotyayev, "Statistika," 11,000 copies, 160 pages]

[Text] In this book the authors analyze the structure and principal parameters of existing data processing systems. They classify and indicate the specific features of operation of these systems at enterprises and production associations. The authors devote considerable attention to problems of designing industrial processes of data processing and the principles of their organization. Methods elaboration of evaluation of the economic effectiveness of solving both individual functional problems of control and management and of the system as a whole is the most important item from the standpoint of improving data processing systems.

This book will be useful to specialists in development and improvement of control and management systems in various branches and elements of the nation's economy as well as to studnets of the corresponding areas of specialization at higher educational institutions.

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Chapter I. Organization of a Data Processing System

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PUBLICATIONS

LIST OF SOVIET ARTICLES DEALING WITH COMPOSITE MATERIALS

Moscow GOSUDARSTVENNYY KOMITET SOVETA MINISTROV SSSR PO NAUKE I TEKHNIKE. AKADEMIYA NAUK SSSR. SIGNAL'NAYA INFORMATSIYA. KOMPOZITSIONNYYE MATERIALY in Russian Vol 4, No 6, 1978 pp 3-5

[Following is a listing of the Soviet entries from SIGNAL'NAYA INFORMATSIYA. KOMPOZITSIONNYYE MATERIALY (SIGNAL INFORMATION. COMPOSITE MATERIALS), a bibliographic publication of VINITI. This listing is from Vol 4, No 6, 1978]

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3. Structure and Properties of Reinforcing Elements

25. "Mechanochemical Transformation of Polymers," Oprea, K. V. MEKH. POLIMEROV, No 6, 1978, pp 977-988.

4. Methods of Producing Semimanufactures of Composite Materials

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