RELIABILITY OF THE FUNCTIONING OF THE WATER SUPPLY AND SEWERAGE SYSTEM

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Summary. *The article concerns the property of reliability, as basic part of quality of the water supply system. Main aspects of reliability are described. Directions of security of reliability, structural security of reliability, control of reliability are observed. Structural and temporal redundancy of security of reliability, preventive system and the water supply and sewerage systems are covered. Property of maintainability as one of reliability items is defined.*

Key words: *the water supply and sewerage system, reliability, quality, technical state, maintainability, service, repair, operation.*

INTRODUCTION

The water supply and sewerage system occupies major place among a lot of branches of modern technique, guided on raise of people's living standards, an accomplishment of human settlements and an industrial development.

The security of the population by pure, good-quality water has major hygienic significance as it protects people from the various epidemiological diseases transmitted through water. The feed of enough water in a human settlement allows to lift a common level of its development. For users' satisfaction, the enormous amounts of water are required, sometimes attaining to thousands cubic meters a day.

The security of the reliability of the water supply and sewerage systems, as well as to all service systems, is one of the primal tasks in their projection. The system should be projected and constructed to be capable not to execute the functions only, but also to supply their uninterrupted fulfilment in the preset extent actually in the process of use. As a function of the water supply systems is to supply the water for users in amounts demanded by it (according to the preset regime of consumption) and demanded quality, it is possible to consider, at an actual fulfilment of these conditions, that the system is in "operable state".

If because of any reasons a normal performance of the system is damaged and decrease of a quality of service of installation exceeds admissible (provided by standards) so the system "failure" occurs. The breaking of system's functioning can occur because of intolerable long-term break or temporal decrease of water delivery to installation of supply, intolerable decrease of the preset pressures in a water-supply line, deterioration of quality of the given water.

Lots of various events can be cause of failures: faults of lines of water transportation (water ducts, a primary circuit), defects of pumps and electric power stopping delivery on pumping stations, intolerable level recession of water in a radiant of the water supply or pond water pollution. Some of the named events can cause even the absolute (temporal) water failure to supplied installation. Most of the events calling a quality's fall of the service are fortuitous, which are not possible to foresee and to prevent [17].

As the majority of water delivery' failures is called by various occasional events, the numerical evaluation of reliability of the water supply system has probable character and can be gained by the analysis and machining of the statistical data accumulated as a result of recording of similar events.

According to an official nomenclature, "reliability" is defined «as a property of an object to perform specified functions, keeping in a time the values established parameters».

To the basic reliability indexes of systems, structures, installations, devices refer to:

- The probability of their trouble-free operation, i.e. probability of no failure during the operating time;
- Failure rate, i.e. the probability of failure for an observed point of time.

STATEMENT OF PROBLEM

The quality played out in a time is termed as reliability, that is property of an object to perform specified functions, keeping in a time the values established parameters in the necessary limits matching to the preset regimes and use conditions, mechanical services, repairs, storage and transportation.

The reliability of processes, as well as in case of the reliability of service, is the complex index of a quality defining a possibility of process to supply a quality of process consistently at the fixed cost price and productivity.

The quality and the reliability of the technical system are the properties which are changed in a time and crossly influence on each other, initial for security, management and improvement of the quality. The quality of the water supply and sewerage systems is sized up on a population of properties to fulfill certain needs according to its assigning.

The reliability is an item of various properties of engineering installation and is stipulated: non-failure operation, longevity, maintainability and a conservability.

The reliability of engineering systems is defined by perfection of their design, constructions and manufacturing methods of the equipment and assembly units, and also depends on an application conditions, service and repair in many respects. In different concrete events any property defines the property of the installation's reliability in better extent, but any of them does not define reliability completely [20].

The conditions of normal operation, and also the reasons of falling out of the water supply and sewerage systems are diversiform and depend on many factors. They are defined by the quality of projection, manufacturing of the equipment, building, mounting and operation. The monitoring, maintenance and restoration of an operable state of the water supply and sewerage systems are the most important problem of engineering exploitation for security of a demanded reliability level, at the preset longevity and technical-and-economic indexes.

With allowance for up-to-date availability index of product of a feeding system of water and the outfall with the considerable deterioration of main funds, and also overwork and ineffective use of material and power resources a special role for quality indexes and reliability renders maintainability of the water supply and sewerage systems and its devices. Maintainability is a property of an engineering system and its devices which includes the adaptiveness to forestalling and discovery of reasons, faults, to maintenance and restoration of an operable state by conducting of mechanical services and repairs.

Making of the controlling systems preventing negative aftereffects of processes, flowing past in the water supply and sewerage systems, being an embodiment of a principle of adaptation and self-regulation not only for working functions of system, but also for its quality indexes' saving .

The quality is a perspective direction for the complex systems and the gears, working in an intense application conditions what the water supply and sewerage systems are.

QUALITY ASSURANCE OF THE COMPLEX ENGINEERING SYSTEMS

The quality assurance of the complex engineering systems is the complex problem including a number of interdependent aspects, due to the operating factors defined by principles, methods and resorts of security and maintenance of demanded reliability indexes (fig. 1).

The practice of making and operation of the water supply and sewerage systems confirms three main aspects of the reliability: system (structural), including methods of their system architecture at the stage of projection; technological, referring to a production phase, the buildings, including methods of manufactures of the equipment, refining materials' properties, and also tests, starting and adjustment, engineering following up of items in production; embracing principles and an assembly method, adjustments, operation, diagnosis, mechanical services and repair.

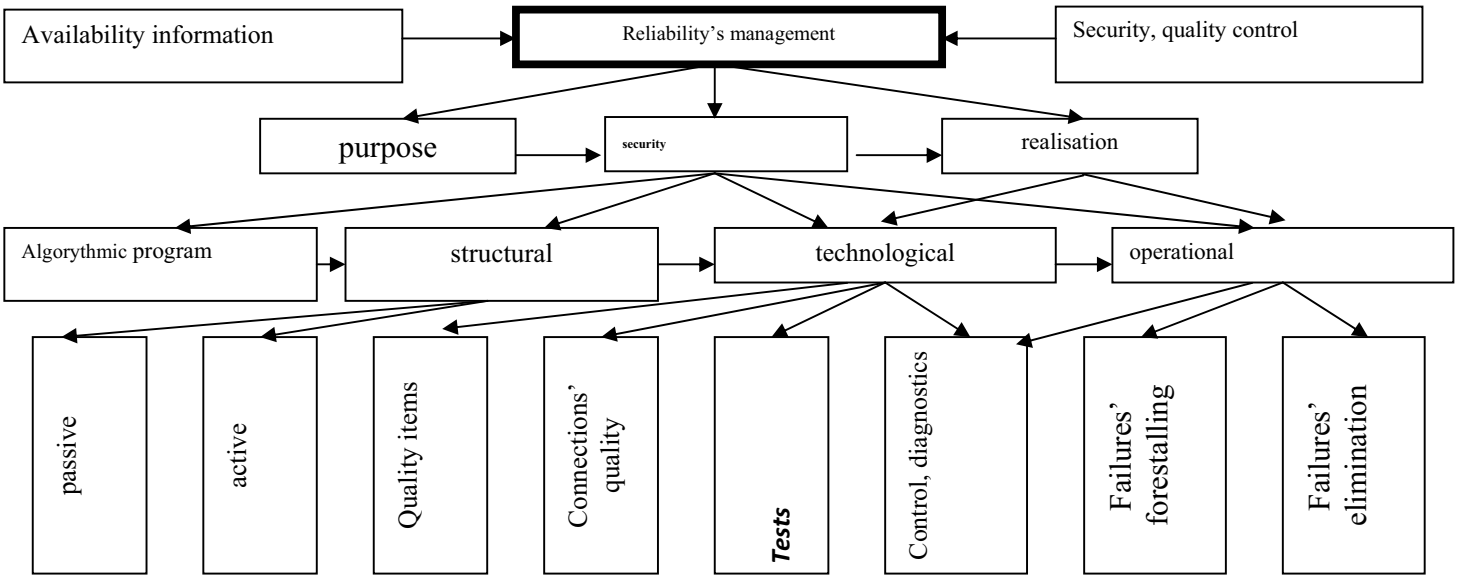

Fig.1 the Scheme of security of reliability WDS

The most perspective direction of security of reliability of the water supply and sewerage systems, allowing considerably increasing its efficiency is the necessity to consider making of conditions and methods of active security of reliability at all stages of life cycle. At the first stage at projection of assembly units and systems with allowance for all aspects in their close interconnection it is attained by means of a justification of matching structural, functional and constructive schemes of the water supply system, and also element and materials' supply. The rational structure, from the point of view of reliability, develops at the binding account of all basic processes attending performance of the water supply system, and also prospective regimes and conditions of their operation.

At the stages of manufacture and operation the mortgaged reliability level is implemented and expended. So, the production and the water supply and sewerage systems' operation should be produced proceeding from problems and the possibilities mortgaged at the first stage of making the system. Maintenance of a high level of reliability during the long-term operation at a modification of its regimes and conditions in wide diapasons supplied at use of a possibility of self-organizing of the complex systems, and also active control in their parameters.

At the system's installation in operation, a main condition of security of an operable state is the control of mounting and adjustment quality. The properties mortgaged at projection and parameters of assembly units, the equipment in the course of its manufacture are not reproduced with an absolute accuracy, and diverse conditions of mounting, adjustment, exploitation differently influence intensity of processes of a modification of service capability and augment these differences even more. Therefore knowledge of passport properties and parameters of system components of the water supply and sewerage systems is insufficient for their correct use, mechanical services and repair [19].

STRUCTURAL SECURITY OF RELIABILITY

A main singularity of the water supply and sewerage systems is inequality in a time of parameters and recurrence of operation. This singularity is a defining condition at the solution of a problem of structural security of reliability of the water supply system and the outfall at the stage of their projection. So, interlocking of functions, characteristic of the water supply system allows observing minimum structure as system within bridge and sequentially connected devices, and properties of mass allocation of feeds to use for engineering realization of idea of subsystems of security of reliability.

Structural security of reliability of the water supply and sewerage systems represents an essential part of common system of security and quality control. It is carried out at the expense of purposeful development or a modification of the block diagram of the water supply and sewerage systems in its projection. Subsystems of security the reliabilities inducted into a system structure of the water supply and the outfall, maintaining of demanded reliability realize active impact on its devices for the purpose. The strategy of implementation and expending of an operational life of assembly units of the water supply and sewerage systems, i.e. a production process and exploitation methods, also should develop on a projecting phase [9].

The basic peculiarities of the water supply system and tap of drainages are their mass character, duration of production of base models of assembly units and the equipment, and also the long-term expected life till 20 and more years. These singularities essentially complicate conditions of security and control of reliability and quality of such systems.

Even for an up-to-date level of development of technique and production engineering, it is very difficult to supply with a rational fashion reliability of the water supply system created for the long-term time of production and exploitation in the conditions of restricted financial resources. In this connection there is a problem of development of design techniques and operation of the water supply and sewerage systems, based that structural and constructive schemes of systems should guess an optimalising control of the operational factors supplying desired values of reliability indexes. Scheduling of operation of the water supply system and the outfall should be yielded with allowance for these possibilities.

Subclasses of structural security of reliability.

For security of a demanded quality level of the water supply and sewerage systems, the control of reliability is carried out impact on the parameters defining reliability. It is possible to observe two subclasses of structural security of reliability: active and passive. Active structural security of reliability provides injection in a system structure of the water supply and sewerage systems of subsystems of security of the reliability, realising the forestalling and removal of possible operational failures. The subclass of passive security of reliability of the water supply system and a tap of drainages introduce traditional structural methods: stores on parameters, redundancy of devices, systems, subsystems, etc. Exploitation of the water supply and sewerage systems with subsystems of security of reliability should guess rational control in its structural parameters in the course of the long-term performance. Redundancy of devices, subsystems, and also stores by parameters are possible to use if the power limitations allow, costs, or if any other alternatives are hard to realise in the given system.

The security of reliability by means of redundancy and stores on parameters in hydromechanical systems at stochastic loadings has certain complexities. Designs of hydraulic, mechanical and hydromechanical systems in such conditions do not allow to supply full redundancy as it demands magnification material - and power consumption.

An application of resorts and methods of an automation on the basis of measuring and computing device for control in parameters of reliability of the water supply and sewerage systems in the course of their operation is one of principal directions of raise of their technological level. Therefore in modern systems of water feed and the outfall in view of their considerable cost, complexity, energy content and an automation large-scale, statement and a problem solving of a quality assurance and reliability demand application of special control devices.

CONTROL OF RELIABILITY

For control the reliability of the water supply and sewerage systems it is necessary to apply approaches and methods of the theory of automatic regulation. Generally the control action is formed depending on a controlled quantity modification, and also from external influences. The control action generally is represented in the form of a functional:

$$R = F\left(x_i, v_i, \frac{dx_i}{dt}, \ldots, \frac{dv_i}{dt}, \ldots, \int x_i dt, \ldots \int v_i dt\right) \quad (1)$$

Where x - a controlled variable; v - parameter of external influences; $\frac{dx}{dt}$ and $\frac{dv}{dt}$ - derivatives on a time from parameters of regulating and external influences, accordingly,

that is velocities of a modification of parameters; $\int_t xdt$ and $\int_t vdt$, integrals on a time from parameters of regulating and external influences, that is the accumulated modifications of parameters.

Automatic-control systems consist of two main bodies: a controlled plant and a controlling system. A controlled plant in our event can be the water supply and sewerage systems, and its separate subsystems, the hydraulic equipment, pipelines, an accessories or their devices (fig. 2).

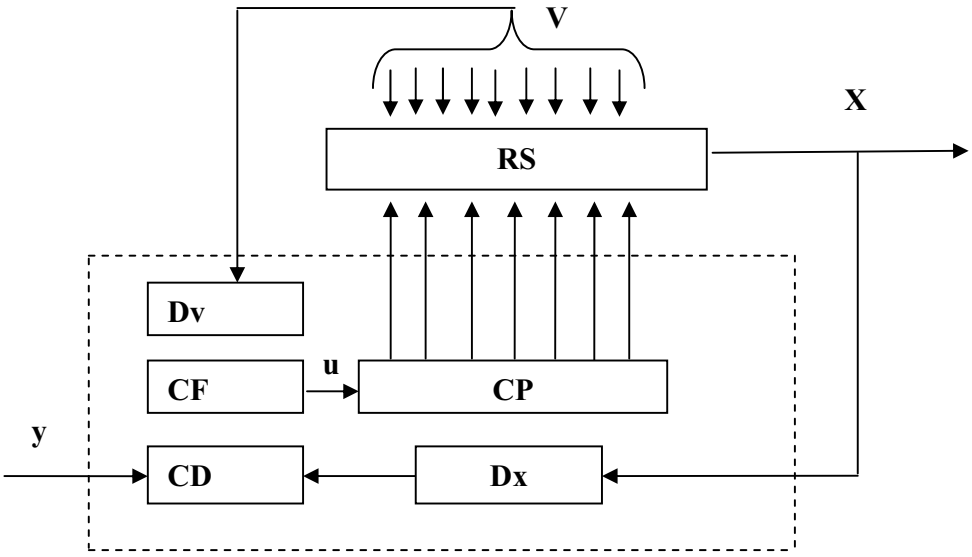

Fig.2. the Control diagram the processes defining reliability of RS:

v - Operating deflexions; x - an adjustable exit pupil; y - parameter stipulated THAT; u - control action; D_x - the sensing element for exit pupil recording; D_v - the sensing element for recording of operating deflexions; CD - a comparison device; CF - a converter facility; CP - the control package.

The control of reliability of the water supply and sewerage systems at the stage of projection guesses security of a necessary reliability level by mining of rational structural and constructive schemes, and also separate systems; determination and security of inter element couplings and systems, including exterior. At projection account of a complex of parameters of the water supply and sewerage systems and determination of ratios between them, justification of operating duties of operation, a possibility of monitoring, regulating, control in all parameters which define reliability, and also a justification of systems of mechanical services, repair and maintainability are executed.

Engineering implementation of resorts of security and control of reliability of the water supply system and the outfall can be various.

Supplying subsystems can be implemented injection in system of secondary members or connections which can operate:

Constantly during the work of the water supply and sewerage systems

Periodically they are put into work automatically by the subsystems which are a part of the water supply system and the outfall which change its structure, adjust, cancel, turn out or remove a load part at excess of a tolerance level by it;

They put are into work periodically by operator-diagnostician systems and the subsystems supplying control by reliability of the water supply and sewerage systems including of the person.

STRUCTURAL AND TEMPORAL REDUNDANCY

The structural and temporal redundancy inducted into system components of the water supply and sewerage systems for the purpose of security of reliability has two types:

- If it is not affect the basic solutions accepted at synthesis of a main system, that is at an invariable method of performance, structure and character of its constituent parts;
- If it leads to a basic change of structure and principles of performance of separate parts of a main system and of the whole developed system.

The simple redundancy of devices and subsystems with their automatic connection can be an instance of the first type of structural redundancy. For example, binding disposition of cross connections with shut accessories on pipelines, application not less than two pressure-tight and inlet manifolds on pumping stations. An installation not less than two working pumps and one or two backup, application not less than two pressure tunnels and sewers for water delivery and a tap of drainages, use not less than two structures of refining, both water, and a sewage liquid. Application not less than two radiants of water diversion, security of an additional moisture reserve, at the expense of availability not less than two clear-water basins, etc.

The second type guesses constructive and the structural alterations inducted in the form of redundancy in system of reliability for the purpose of security of demanded quality of giving of services. For example, injection of breakage of a stream in systems where additional hydraulic loads are possible at concealment shut accessories with possible regimes of a hydraulic impact in a net. So, for security of the complete correspondence of a water consumption and water delivery by a pumping station of the second ascending gradient frequently it is not always granted possible. Therefore for trusty security of water supply to users, water supply regulation and consumption apply the capacity structures to security of a store and a water storage. Controlling capacity structures on a net allow to supply a controlled regime of their filling and dump within days and submission, in the final reckoning, to a problem of maintenance of pressures in a net in predetermined thresholds, supplying thus absence of accidents in-process the water supply system and reliability of water feed to users.

SYSTEM OF PREVENTIVE-MAINTENANCE OVERHAULS

The quality of the water supply and sewerage systems depends on the reliability of operation of its structures as a whole. The important fact of reliability is the water supply and sewerage systems life cycle. Now there is no sufficient statistical material on domestic water supply systems on which base it would be possible to install numerical ratios of such agency. However foreign data testify, that the more working lifespan of the systems is, the more high level of magnitude of damageability, failure, non reparability. It is caused by an ageing as water feed systems as a whole, and its separate devices. The range of items and the equipment, applied to the water supply as a rule and the sewerage system, is extremely diverse: pipes, pump units, electro motors, electrics, various sorts of a network accessories, control and measuring and other gears, resorts of automation, computing machinery and the others.

It is obvious, that the ageing of the indicated items and the equipment is imminent, and process of an ageing (deterioration) happens according to some common regularity for all transferred devices. In a cut-in after putting in operation of a fault of devices are watched rather often: the admitted imperfections affect at their mounting and starting, a device' adaptiveness to operation normal conditions. Then there is a period of a stable operation phase, when faults are rare. At last, phase of heightened frequency of faults (outcome of an ageing), completed by approach of the limiting state

starts to be watched. To this phase devices should be in time substituted.
For the forestalling of deterioration of structures and the equipment, accident precaution, duly substitution of the devices which have served the rated time, security of fail-safe operation of the water supply system and a tap of drainages, and also quality of giving of services is applied system of preventive-maintenance overhauls (PMO).
System PMO includes organizational-engineering measures for supervision and care of structures and all sorts of the repair, realised periodically under in advance made plot. The order and times of conducting PMO regulate operating instructions and matching rules about conducting PMO.

One of perspective paths of system development of the preventive-maintenance overhauls, allowing on the basis of the account of actual availability index of product of the concrete water supply system to devide out an amount unscheduled and to refine use of an operational life of its devices, application of methods and monitoring aids of availability index of product and diagnosing which precedes mechanical services fulfilment is, and its outcomes serve for definition of the enumeration and volume of forthcoming operations.

THE WATER SUPPLY AND SEWERAGE SYSTEMS DIAGNOSING

Diagnosis executes three trial functions:
- Data acquisition about availability index of product of the water supply and sewerage systems, their knots and assembly units;
- Machining and the analysis of these data;
- Preparation or decision making about volumes and times of conducting of mechanical services or repair.

The effective valuation of availability index of product of the water supply and sewerage systems is executed at the solution of primal problems of diagnosing:
- To a functional test;
- Searching, localisation of imperfections and derangements;
- Data acquisition for prediction of the residual operational life;
- To statement of the diagnosis and preparation (adoption) of the solution on control of availability index of product of cars.

The developments in the field of engineering diagnosis of hydraulic systems are directed now on the solution of the indicated problems. The major attention is on making of progressive methods, and perfecting of diagnostics tools simultaneously with the continuous raise of level of testability assembly units of reliability of systems.

The water supply and sewerage systems diagnosing can be conducted on a various step on levels:
1 level - definition of the functional service capability of the water supply system as a whole;
2 level - definition of parametric service capability;
3 level - definition of the functional failures of devices;
4 level - definition of parametric failures of devices;
5 level - definition of causes of a failure of a device;
6 level - definition of concrete magnitude of failure.

Amount of possible states from nominal to a maximum value of diagnostic parameter which can be discriminated by means of a gear:

$$N_j = \frac{X_{npj} - X_{nj}}{\Delta X}. \qquad (2)$$

Where: N - an amount of possible states; X_{npj} и X_{nj} - the limiting and nominal parameter values for j devices; ΔX a-receptiveness for measuring of the given parameter.

Taking the logarithm N on the base 2 we will gain an amount of information in bats about a state j devices:

$$I_j = \log_2 N_j = \log_2 \left[\frac{X_{npj} - X_{nj}}{\Delta X} \right]. \qquad (3)$$

The net information on each level size up by formula:

$$I_i = \sum_{z=1}^{l} \left\{ \sum_{j=1}^{m} K_j \cdot \log_2 \left[\frac{\left(X_{npj} - X_{nj} \right)}{\Delta X} \right] \right\}. \qquad (4)$$

Where I_i - an amount of information on i to level; z - number of the parameters metered at the accepted method of diagnosing; K_j - an amount of j devices in system.
The complete diagnostic information on system will develop of the information on levels:

$$I_\Sigma = \sum_{i=1}^{6} I_i. \qquad (5)$$

The comparison by the given measure has displayed, that the greatest amount of information for the standard module of hydraulic systems is gained by means of the gears implementing a statparametric method, which switches on flow sensors, pressure sensors and temperatures, and a control device with a known water resistance. Such type of equipment as of today is the most suitable in the capacity of base for making of an overall system of diagnosis of assembly units of pumping stations of the water supply and sewerage systems.
Effective method of detection of places of derangements in hydromechanical systems is local diagnosing with division of system into subsystems for which there is a diagnostic information on associations. At local diagnosing was possibly check of assembly units of system without their disassembling and removal. At preparation of conducting of local diagnosing:

The enumeration of assembly units of system which will be troubleshot is defined;
The sequence of diagnosing of assembly units from the enumeration is installed;
The procedure develops and diagnostics tools of assembly units are selected.
The enumeration of assembly units of diagnosing of the water supply and sewerage systems is defined on assay values of operation failures and derangements of a water distribution system and water removal, and also depending on their schemes and design features. The optimum sequence of diagnosing of assembly units of the water supply system and a tap of drainages is defined from a condition:

$$\overline{T}_1 \cdot P_1 \le \overline{T}_2 \cdot P_2 \le \ldots \le \overline{T}_i \cdot P_i \quad , \tag{6}$$

where: $\overline{T}_i$ - the relative complexity of diagnosing of the assembly unit; $\overline{P}_i$ - the relative operational life of the assembly unit.

The relative complexity of diagnosing $i-$ того of the assembly unit is defined under the ration:

$$\overline{T}_i = \frac{T_i}{T_{\max}}, \tag{7}$$

where: T_i - complexity of diagnosing $i-$ того of the assembly unit; $T_{\max}$ - maximum complexity of diagnosing of the assembly unit from the accepted enumeration.

The relative operational life $i-$ того of the assembly unit is defined under the ration:

$$\overline{P}_i = \frac{P_i}{P_{\max}}, \tag{8}$$

where: P_i - $\gamma\%$ operational life $i-$ того of the assembly unit; $P_{\max}$ - maximum $\gamma\%$ an operational life of the assembly unit from the accepted enumeration.

The estimation of the relative complexity of diagnosing is defined for each water distribution system and the outfall depending on access to its devices, and also check sorts. Approximately it is possible to consider, that check of assembly units without disassembling of pipelines - $T = 0{,}1$; connection of gears of diagnosing - $T = 0{,}5$; check with disassembling of pipelines $T = 0{,}6\ldots1.0$.

The relative operational life of system components of water supply and tap of drainages is defined on their rating.

After definition of sequence of conducting of diagnosing and sampling of methods and diagnostics tools local diagnosing can be executed. At discovery of the first defective device yield its substitution or repair, with the subsequent diagnosing. In an event if the water supply and sewerage systems start to work properly, the diagnosing should be completed.

CONCLUSIONS

One of key parameters of the water supply and sewerage systems quality is their reliability. Therefore for security, control and martempering of quality of the water supply system and a tap of drainages are necessary objective measuring methods and controls of reliability and its components.

Depending on availability and character of initial data quality control and reliability of the water supply and sewerage systems can be determined, stochastic and adaptive. Two first types of control guess availability of the equations of installations of control and negative impacts or control routines of a various sort. In an event when the indicated premises are unknown, apply an adaptive technique. The probabilistic approach of iterated methods is thus used. At a problem solving of control of reliability of the water supply system known research techniques of processes, self-acting, adaptive, a hierarchical control can be used.

The algorithm of searching of derangements of assembly units of the water supply and sewerage systems are offered at local diagnosing which allows to lower complexity of operations on their discovery, and also on a discovery time.

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НАДЕЖНОСТЬ ФУНКЦИОНИРОВАНИЯ СИСТЕМ ВОДОСНАБЖЕНИЯ И ВОДООТВЕДЕНИЯ

В статье раскрыто свойство надежности, как базового элемента качества системы водоснабжения. Приведены главные аспекты надежности. Рассмотрены направления обеспечения надежности, структурное обеспечение надежности, управление надежностью. Освещены структурная и временная избыточность обеспечения надежности, планово-предупредительная система и диагностика системы водоснабжения и водоотведения. Приведено свойство ремонтопригодности, как одного из слагаемых надежности.

Ключевые слова: система водоснабжения и водоотведения, надежность, качество, техническое состояние, ремонтопригодность, обслуживание, ремонт, эксплуатация