CHOOSING A MAINTENANCE STRATEGY FOR ENSURING THE OPERATIONAL RELIABILITY OF MEDICAL EQUIPMENT IN THE CONTEXT OF THE ELECTRICAL SAFETY

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Abstract: The article focuses primarily on the three typical states of modern electronic equipment: operational state, state of failure and state of recovery. The failure state (SF) and the operational state (SO) are characterized by the probabilities of residence in each of them – failure probability Q(t) and probability of failureless operation P(t).
The aim of this paper is, as a result of a study of the case studies related to the operational reliability of different in type and complexity electronic systems, several different concepts for conducting maintenance have been developed, proposed and analyzed. The strategies are proper and for medical equipment. In conclusion, the most appropriate maintenance strategy is proposed for the purpose of ensuring a high degree of electrical safety in the maintenance of medical equipment.

Key words: Medical Equipment, Maintenance Strategy, Operational Reliability, Electrical Safety

ИЗБОР НА СТРАТЕГИЯ ЗА ТЕХНИЧЕСКОТО ОБСЛУЖВАНЕ ЗА ОСИГУРЯВАНЕТО НА ЕКСПЛОАТАЦИОННАТА НАДЕЖДНОСТ НА МЕДИЦИНСКА АПАРАТУРА В КОНТЕКСТА НА ЕЛЕКТРОБЕЗОПАСНОСТТА

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Abstract: В статията е поставен акцент преди всичко на трите типични състояния за съвременната електронна техника: работоспособно състояние, състояние на отказ и състояние на възстановяване. Състоянието на отказ (S_O) и работоспособното състояние (S_P) се характеризират чрез вероятностите за пребиваване във всяко от тях – вероятност за отказ $Q(t)$ и вероятност за безотказна работа $P(t)$. Целта на настоящата статия е, в резултат на изследване на казусите, свързани с експлоатационната надеждност на различни по тип и сложност електронни системи са разработени, предложени и анализирани няколко различни концепции за провеждане на техническото обслужване. В заключение се предлага най-подходящата стратегия за техническо обслужване на медицинска апаратура за целите на осигуряване на висока степен на електробезопасност.

Key words: Медицинска апаратура, Техническо обслужване, Експлотационна надеждност, Електробезопасност.

1. SPECIFICITY OF THE PROBLEMS RELATED TO ENSURING OPERATIONAL RELIABILITY AND MAINTENANCE OF MEDICAL EQUIPMENT

The well-known methods for modeling and analyzing the availability and failures of the electronic equipment ensure high precision and accuracy of mathematical reproduction of reliable condition. But, due to the need to describe a huge multitude of possible states [1], in systems with a more complex structure, Markovian models and semi-Markov models are suitable.

With sufficient accuracy for the practice, the vast array of the states could be reduced to four generalized, practically significant states (Fig. 1) by which mathematically to interpret the maintenance process [2,3]:

- Operation state - operability (S_W);
- Prefailure state (S_{PS});
- Failure state (S_F) and recovery state (S_R) of medical electronic systems.

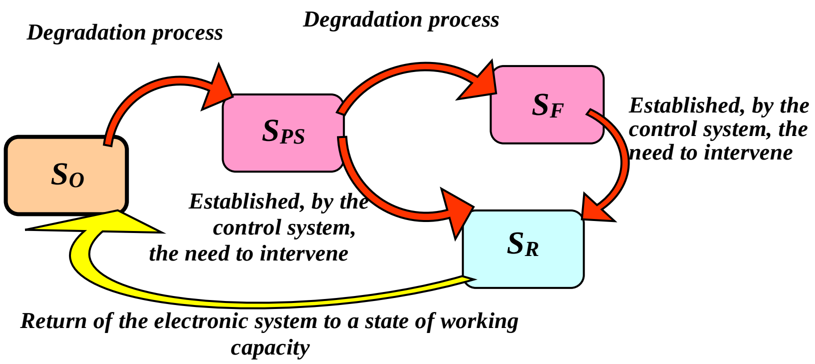


Fig 1. Maintenance transitions diagram represented by four generalized, practically significant states [4]

The article focuses primarily on the three typical states of modern medical (electronic) equipment: operational state, state of failure and state of recovery. The failure state (S_F) and the operational state (S_O) are characterized by the probabilities to be in each of them – failure probability Q(t) and probability of failureless operation P(t).

The aim of this paper is, as a result of a study of the case studies related to the operational reliability of different in type and complexity electronic systems, several different concepts for conducting maintenance have been developed, proposed and analyzed. The strategies are proper and for the medical equipment. In conclusion, the most appropriate maintenance strategy is proposed for the purpose of ensuring a high degree of electrical safety in the maintenance of medical equipment.

2. MAINTENANCE STRATEGIES FOR MEDICAL DEVICES

The concept of „maintenance strategy" can be formulated as a regulated system of rules included in the composition of maintenance, according to which decisions are taken concerning: the volume and types of preventive and emergency repairs of the systems, the duration of the preventive maintenance period, the starting point for reporting the preventive period, the mode of rotation of the prophylactic and emergency repairs, the determinative criterion for making decisions on the type and volume of prophylactic activities, etc.

In the maintenance process the subjective factor must affect the electronic systems in proportion to the level of their degradation. The repairing effects on electronic systems are in principle as diverse as the factors causing their degradation. The criteria by which the repairing impacts could be differentiated are also diverse.

In order to ensure the necessary operational reliability, the time when the repair procedures are started is also essential. From this point of view, repair activities can be separated into two summary groups - preventive repair (with a subjectively established need for intervention) and emergency repair (with objectively arose, visible need for repair).

The prophylaxis of the electronic system is a set of preliminary (preventive) examinations of individual elements and blocks, control and regulation of the changed parameters, replacement and repair of failed components and a number of other measures aimed at increasing its operational reliability.

Prophylactic activities are applied in a strictly defined sequence (which can be described by a repeatedly branching algorithm) specific to different electronic systems, such as: disconnection from operation of the system, visual examination of electronic components and modules, measurement of controlled parameters – if all parameters are within the permissible limits – inclusion of the system in operation; if any/some of the parameters are outside the permissible limits - conducting additional measurements (before and/or after dismantling the relevant electronic modules), diagnostics, localization of the failed block/element, dismantling, repair of the failed element/block or its replacement with a new one, installation, adjustment and adjustment of the parameters until reaching the permissible limits, switching on the system and functional control.

Unfortunately, the prophylactic repairs are accompanied by at least three undesirable effects: significant material costs due to the need to use highly qualified labor and expensive specialized equipment; unjustified deterioration of the standby factor due to a reduction in the time in which the electronic system operates; occurrence of "post-prophylactic" failures.

In order to reduce the impact of the listed negative phenomena, it is necessary to optimize both the organization and deadlines for the prophylaxis, as well as the content and consistency of prophylactic activities. The listed activities are the main attributes characterizing the maintenance strategy.

Unfortunately, in the reliability theory there is not place the necessary emphasis on problems concerning the prophylactic activities. Often, problems related to the volume and types of prophylactic and emergency repairs, the time limit for prevention and the starting point for its reporting, the approach in alternating prophylactic and emergency repairs, as well as the criteria for making decisions on the volume of repairs, are solved intuitively – according to the subjective judgment of the maintenance team, decisions based almost always on a priori empirical experience. A problem that is facilitated by the fact that the information gained from a priori empirical experience has a specific, highly individual character, due to the diversity of electronic systems (in terms of application, structure, element base, degree of redundancy of elements and modules in it, its role in preserving human life, etc.).

This information therefore has no universal applicability and this is the main reason why serious errors have been made in the maintenance of electronic systems. Errors causing sometimes a very serious decrease in their operational reliability.

The classification of maintenance strategies for electronic systems according to depending on this how preventive and accident repairs are rotated, maintenance strategies are classified as:

2.1. ACCIDENT’S MAINTENANCE STRATEGIES

The transition diagram, of the strategy thus formulated, is presented in Fig. 2 and Fig.3 [4], where

- Visible felure (S_{VF});
- Unvisible felure (S_{UF});
- Accident’s recovery state (S_{AR});
- Failure rate - Visible λ_{VF} and Unvisible λ_{UF}
- Repair rate - μ

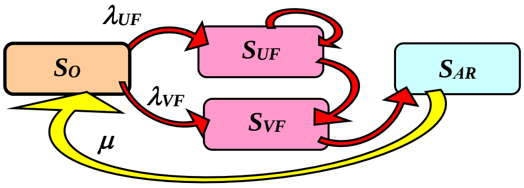


Fig. 2. Diagram of transitions in maintenance strategies including only accident's repair procedures leading to full repair of operability [4]

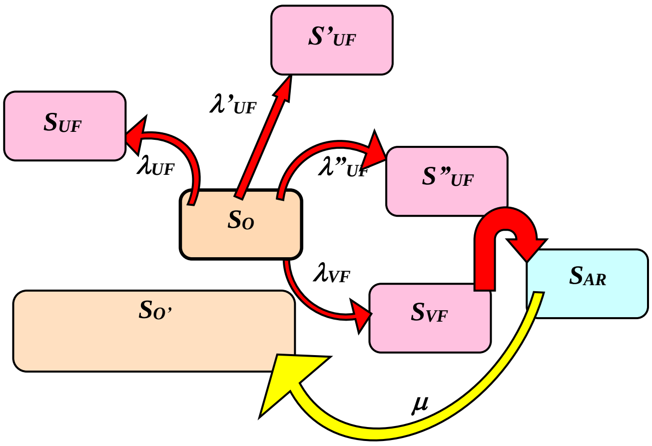


Fig. 3. Diagram of Maintenance Strategy transitions including only accident's repair procedures leading to partial repair of the operability procedures leading to partial repair of the operability [4]

2.2. BLOCK MAINTENANCE STRATEGIES

The diagram of the transitions of the so formulated version of the strategy, is presented in Fig. 4 [4]:

- Operation's state – partly operability (*S'o*);
- Unvisible failure - respectively undetected S'_{UF} and detected S''_{UF}. The same for λ_{UF};
- Accident's recovery state (S_{AR}).

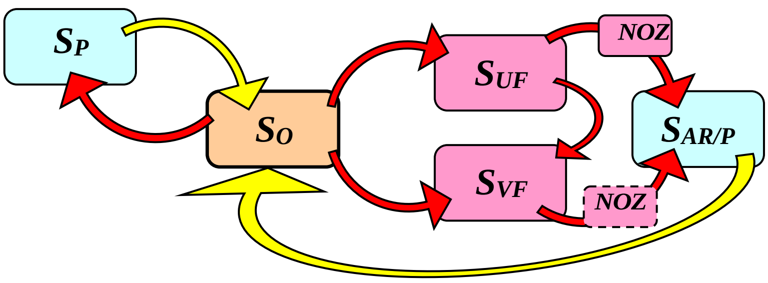
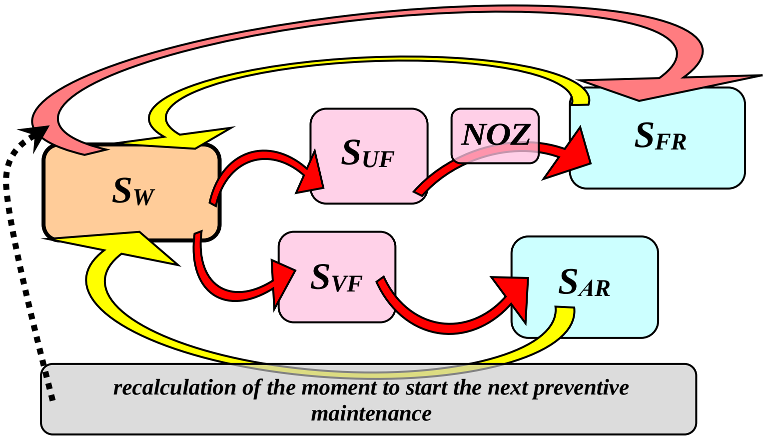


Fig.4. Diagram of the transitions in a Block Maintenance Strategy with zones of non-operating zones [4]

2.3. STRICTLY PERIODIC MAINTENANCE STRATEGIES – Fig.5. [4]

- Profilactic state (S_P);
- Accident's recovery state / profilactic state ($S_{AR/P}$);
- *NOZ* - non operating zones.



Фиг. 5. Diagram of the transitions at strictly periodic maintenance strategies [4]

Strategies for Accident maintenance are perceived those strategies in which full or partial repairs of the electronic system is carried out only after a failure has been discovered.

As Block strategies for maintenance are defined strategies in which the moment for starting the next prophylactic repair of the system is known in advance.

Strictly periodic can be called those strategies in which, after the faulerless operation of the electronic system for a time equal to the period of prophylaxis, prophylactic repairs is carried out, and if a failure has occurred before the expiry of the period of prophylaxis, a full accident repair of the operating capacity of the system is carried out, and the period of prophylaxis begins to run from the moment of completion of this emergency recovery.

3. CHOOSING A STRATEGY AND MAINTENANCE FOR ENSURING THE OPERATIONAL RELIABILITY OF MEDICAL EQUIPMENT

The maintenance analysis of medical electronic equipment is based on the maintenance strategies described above. The authors propose to use time diagrams for a more accurate reading of the residence times of the equipment in all possible states [4, 5, 6, 7].

The following advantages and disadvantages are formulated:

3.1. Accident's maintenance strategies are defined here as strategies where full or partial repair of the electronic system is carried out only after a failure has been established.

This variant of the accident's maintenance strategies is defined as a strategy in which, after a failure occurs, full repair of the operability of the electronic system is mandatory. But the repair is regulated to be done only after finding a refusal – preventive repairs are not provided.

There is an option where, after the occurrence of a failure, full repair of the operation's capacity of the electronic system is not carried out, but only a minimal amount of recovery activities is carried out - to eliminate the established visible failure (and the reasons for its occurrence). No prophylactic control and measurement activities shall be carried out and no setting of the system shall be provided for its parameters to fall within the permissible limits. There is neither a thorough inspection of the printed circuit boards and the elements on them, nor cleaning from the mechanical dirt. This means that some of the hidden failures are not identified and removed, i.e. they remain after the repair activities are completed.

Under this strategy, the electronic system can continue to operate, but without fully restored capacity. Therefore, such a strategy could be applied only to certain electronic systems (household equipment or those whose reliability would not affect the health and safety of people).

Although these strategies involve the least cost, the main disadvantage of all their variants is the low reliability. It is not suitable for life-sustaining devices and those on whose functioning depends the life, health and safety of people.

3.2. The variant of the Block Strategies for maintenance of electronic systems (in the absence of a condition control system) has been accepted as a classical strategy.

This strategy specifies that both accident and preventive repairs should be full recoveries in order to ensure a satisfactory value of the readiness factor. In practice, however, even this is not always a fact.

Block maintenance strategies can be applied in different variants, three of the possible options interesting for practice are:

- Block strategy for maintenance with zones of inactivity;
- Block maintenance strategy with minimal accident and full preventive recoveries;
- Block maintenance strategy with recovers, the volume and duration of which depend on the moment of occurrence of the refusal.

3.3. The Strictly Periodic is this maintenance strategy where if the electronic system has operated unfailingly for a time equal to the maintenance period T_P, it must be preventive repaired, regardless of the technical condition in which it is at that time. If before the expiry of the T_P a failure has occurred (visible), a full accident's repair of the electronic system is carried out, and the period of prophylaxis begins to run from the moment of completion of the accident's repair. If two or more failures occur between two consecutive preventive prophylactics, the moment of completion of the last accident's repair shall be taken as the starting point in the reporting of the time limit for the next prophylaxis.

4. CHOOSING A MAINTENANCE STRATEGY FOR ENSURING A HIGH DEGREE OF THE ELECTRICAL SAFETY OF MEDICAL EQUIPMENT

Effective is the variant of the strictly periodic maintenance strategy, in which preventive repairs are complete repairs of operational capacity. During their implementation, in addition to adjusting the mode of operation, control and correction of the parameters of the equipment to their reference values, hidden failures, if any, must be identified, located and eliminated. For their share to be negligible and this strategy requires a well-functioning continuous condition control system.

The effectiveness of such a strategy is increased in the presence of the electronic control system, which: to fix the exact moment of completion of each recovery (whether it is emergency or prophylactic), to recalculate the time for the start of the next prophylaxis and in the event of an imminent expiry of the prophylaxis - to signal the approach of another prophylaxis so that the service staff can plan the prophylactic activities.

The version of the strictly periodic strategy for technical maintenance is effective, in which preventive repairs are full repairs of working capacity and is mandatory in the field of ensuring electrical safety.

During their implementation in electrical safety, measurements and tests related to establishing compliance with regulated norms are carried out. If necessary, adjustment of the operating mode, control and correction of the equipment parameters to their reference values are made, and hidden failures must be established, localized and removed, if any occurred. In order for their share to be negligibly small and with this strategy, a well-functioning system for continuous control of the condition is required.

In the context of electrical safety, if a failure (manifest) has occurred before the expiration of the prevention period, a full emergency restoration is performed, but the prevention period does not begin to run from the moment of completion of the emergency repairing – Fig.6, but the statutory deadlines are observed, for the following electrical safety observations [8, 9]:

- Fault Loop Impedance - measurement of the resistance and reactance in an electrical circuit that is used to calculate the fault current that flows through the circuit in the event of a fault;

- Periodic measurements to check the operation of the resedual current devaces and for dangerous touch voltages in electrical installations with voltages up to 1000V;
- Periodic measurements to check the protective earthing system;
- Periodic measurements to check the insulation resistance of the safety extra-low voltage circuits in relation to the other electrical circuits of the supply network;
- Periodic measurements of the insulation resistance and leakage currents and etc.

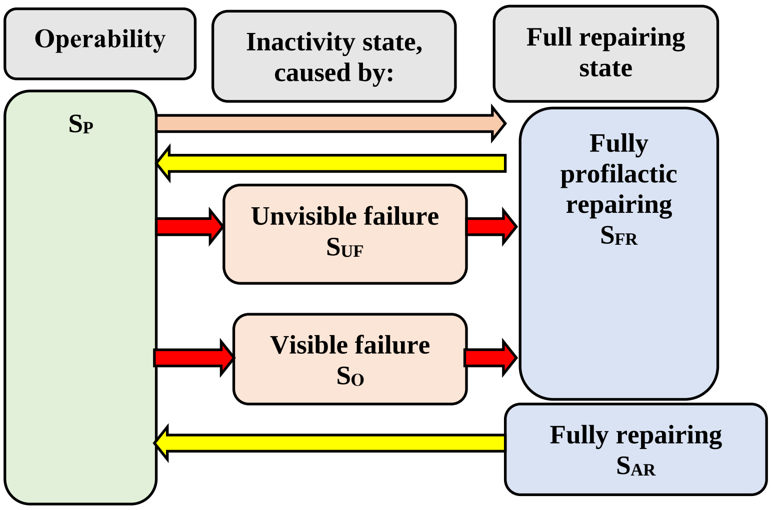


Fig. 6. Diagram of the transitions at Strictly periodic maintenance strategies in the context of the electrical safety

CONCLUSION

The practical experience of applying the strategies defined in the article shows a number of advantages of a strictly periodic maintenance strategy over accident and block strategies.

The advantages of the strictly periodic maintenance strategy over the emergency and block strategies are:

Experimentally, it has been established that the values of mean time between failures increase by 8.1% to 9.2%, depending on the specifics of the equipment. This serious increase in the mean time between failures is mainly due to the lower number of post-prophylactic failures. In addition, although insignificantly, the values of mean time of preventive repairs (from 2.12% to 2.33%) and the mean time of emergency repairs (from 2.31% to 2.42%) decrease. As the main reason for the reduced value of the mean time of emergency repairs, the small number of post-prophylactic refusals can be indicated, and the main reason for the decrease in the values of the mean time of preventive repairs is the lack of campaigniness in the provision of technical service.

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