Structural and Objective Model for Providing a Given Class of Clean Rooms for Microelectronics

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***Abstract*— Based on the system concept, structural and objective model of providing a given class of clean rooms for microelectronics is developed, covering all the reasons and consequences of air purification processes.**

An experimental and analytical method for aerodynamic calculation of air pressure losses in the major elements of the recirculation circuit of clean rooms is proposed. A critical air flow rate is established, at which the air pressure in a clean room approaches the threshold value.

Keywords*— structural and objective model, clean rooms, the system concept, aerodynamic calculation, pressure loss, class of clean rooms.

I. INTRODUCTION

The main feature of the system concept is the dominance of a complex whole over its simple elements. In the traditional concept, the study goes on from the elements to the system, and in the systematic concept, it is necessary to move, on the contrary, from the system to individual elements.

A wide range of problems in human practice has led to a variety of methods and ways of using the methodology of system analysis, which, in turn, involves the development of recommendations for the use of specific approaches for solving the problem.

The basic principles of system analysis were used to develop structural and objective model for providing a given class of clean rooms for microelectronics: elementarism (a system is a set of interrelated elementary components), consistency (consideration of the objects as a system, that is, as an integrity, which is not reduced to a set of elements and connections), hierarchy (a system is a subordinate formation) and formalization (a system can be represented by formal-logical, mathematical, computer, etc. models), and as a procedure - the competence and intuition of specialists, presented in the form of an expert opinion with subsequent evaluation and selection of the most preferred version.

A clean room (CR) for the production of microelectronics is a complicated technical complex. It includes simultaneously operating number of systems and elements with constant monitoring of the technological microclimate of CR. World experience shows that the requirements arising from the concentration of dust particles do not fully reflect all the variety of phenomena associated with the operation of CR. High-quality protection of the object of work from the adverse effects of the internal environment is impossible without taking into account the complex of thermal and aerodynamic processes in air treatment both in the air conditioning and filtration system (ACFS), and directly inside the clean room. Maintaining the parameters of the technological microclimate in CR at the level of a given class is an indispensable condition for the optimal implementation of the main technology [1, 2].

II. RESEARCH METHODOLOGY

Optimization of operational indicators of such a complex is complicated multi-criteria problem containing technical and organizational aspects, which cannot always be formalized. Therefore, the involvement of a systematic concept to its solution in the form of a structural and target model – a "tree" of reasons and consequences (Fig. 1), seems justified.

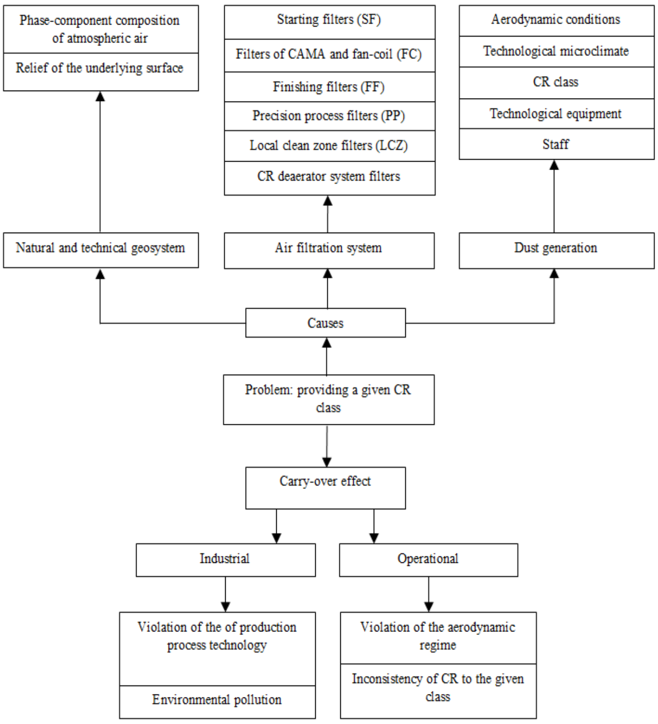

Fig. 1. Structural and objective model of the problem “Providing a given CR class”

The arithmetic mean values of expert estimations for each formulation of the "tree of reasons and consequences" are presented in Table 1.

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TABLE I. EXPERT ESTIMATIONS OF THE REASONS AND CONSEQUENCES FOR THE PROBLEM "PROVIDING A GIVEN CR CLASS"

The causes of the problems		***Numerical score***
Natural and technical geosystem	Phase-component composition of atmospheric air	4.0
	Relief of the underlying surface	1.9
Air filtration system	Starting filters (SF)	4.2
	Filters of CAMA and fan-coil (FC)	4.0
	Finishing filters (FF)	4.5
	Precision process filters (PP)	4.5
	Local clean zone filters (LCZ)	4.2
	CR deaerator system filters (DS)	2.0
Dust generation	Aerodynamic conditions	4.5
	Technological microclimate	4.2
	CR class	4.5
	Technological equipment	4.0
	Staff	4.5
Formulation of the problem consequences		
Industrial	Violation of the of production process technology	4.6
	Environmental pollution	4.1
Operational	Violation of the aerodynamic regime	4.3
	Inconsistency of CR to the given class	4.5

The priority of formulations of reasons and consequences is proposed to be estimated with the help of 10 experts by a 5-point scale: "I agree" with the formulation "Yes" - 5; "rather" agree" than "No" - 4; "my opinion" neither "Yes" nor "No" - 3; "rather "disagree" than "agree" - 2; "disagree" with the formulation -1 [3-6].

The analysis showed that the most significant factors affecting the efficiency of the multi-stage CR filtration system are: phase-component composition of the outdoor air (4.0 points), starting filters (4.2 points), filters of CAMA and FC (4.0 points), finishing filters (4.5 points), PP filters (4.5 points), LCZ filters (4.2 points), aerodynamic conditions (4.5 points), technological microclimate (4.2 points), CR class (4.5 points), technological equipment (4.0 points), staff (4.5 points), violation of PP technology (4.6 points), environmental pollution (4.1 points), violation of the aerodynamic regime (4.3 points), and the inconsistency of CR to the given class (4.5 points), which in turn directly lead to the environmental pollution of the CR, and, consequently, decrease the yield and reduce the environmentally friendly production of microelectronic devices. The hierarchy of tasks for solving the problem under consideration can be represented in the form of a "tree of goals" (Fig. 2).

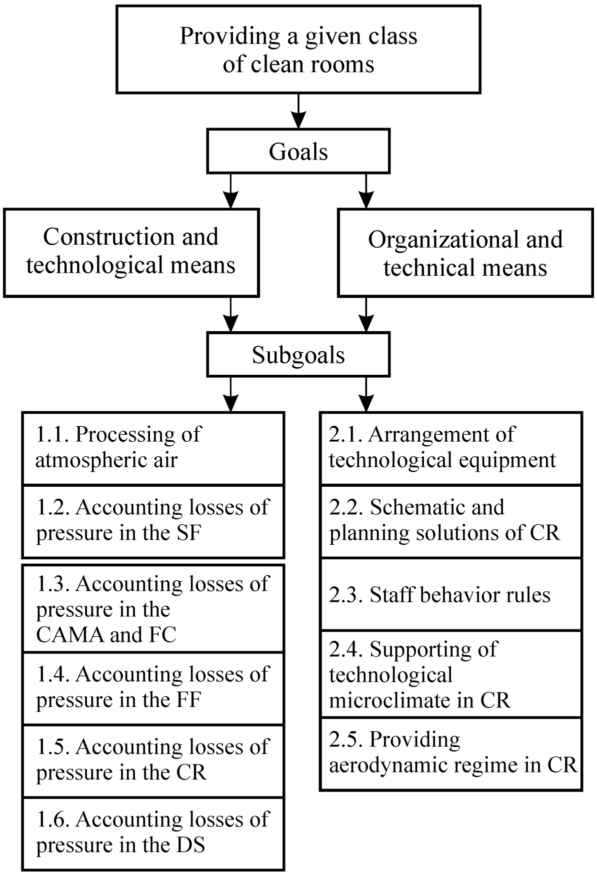

Fig. 2. "Tree of goals" for solving the problem “Providing a given CR class”

The structuring of tasks shows that for solving the basic problems according to the given class CR it should be thoroughly investigated the questions of ensuring the aerodynamic conditions of CR and analyzed the pressure losses in the main elements of ACFS. From the above proposed structural and objective model (figure 1), it follows that the providing a given class 5 ISO for CR depends on the aerodynamic conditions of CR, formed by recirculation circuit (RCC) (Fig. 3), consisting of a fan-coil, pressure (PD) and negative pressure (NPD) ducts, buffer space (BS), finishing filters, hollow floor (HF), under hollow floor space (UHFS) and return air duct (RAS) in the deaerator system.

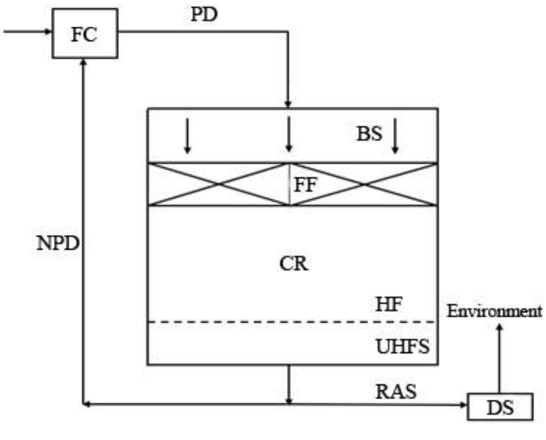

Fig. 3. Structural arrangement of the RCC in CR

The main task of the RCC is air rate and air changes per hour level holding, which requires ensuring an appropriate pressure drop in the main elements of RCC. Therefore, the greatest interest from a scientific and practical point of view for evaluating the effectiveness of SCFV represents the set of aerodynamic processes particularly in this contour.

Total air pressure loss in RCC:

$$\Delta P_{RCC} = \Delta P_{PD} + \Delta P_{UPD}, \quad (1)$$

where ΔP_{PD} and ΔP_{NPD} are air pressure losses in pressure (PD) and negative pressure (NPD) ducts, respectively.

The pressure losses in FF can be determined from the formula:

$$\Delta P_{FF} = \frac{pv^2 Hzc_{hr}\beta}{\pi d'}, \quad (2)$$

where p and v are the air density, and its rate, respectively (kg/m^3 and m/s, respectively); H and d' are the height of the filter layer and the diameter of fibers, respectively (mm); z is the density of the packing equals to the volume of fibers per unit volume of the medium; $c_{hr} = f(Re)$ is the head resistance; $\beta = f(z)$ is a correction for the mutual influence of the fibers in the filter layer.

Expressing the air rate through the air consumption (G):

$$v = \frac{G}{pF_c g}, \quad (3)$$

it can be obtained:

$$\Delta P_{FF} = \frac{G^2 Hzc_{hr}\beta}{F_c^2 \pi d' pg^2}, \quad (4)$$

where F_c is the area of the filter channels, m^2.

Calculation of the pressure P_{CR} can be written in the form:

$$P_{CR} = P_{AR} + P_{GP} = P_{UHFS} + P_{GP}, \quad (5)$$

where P_{AR} is the pressure in adjacent rooms (pa); P_{GR} is the overpressure in CR (pa); P_{UHFS} is the pressure in the under hollow floor space (pa).

When calculating the pressure drop in the hollow floor ΔP_{HF}, we introduce the perforation coefficient:

$$f_p = \frac{F_{PHF}}{F_{CR}}, \quad (6)$$

where F_{PHF} is the area of perforation of the hollow floor (m^2); F_{CR} is the area of CR (m^2). At the same time, it should be taken into account that the main condition for providing the overpressure in CR must be as following: $\Delta P_{HF} = \Delta P_{CR} + \Delta P_{UHFS}$.

Considering the hydraulic resistance HF as the resistance of a flat perforated grid, and replacing the air rate by its air consumption, a pressure drop in HF (ΔP_{HF}) can be obtained:

$$\Delta P_{\mathrm{HF}} = \frac{G^2\left\{\varepsilon_\phi \varepsilon_0 \left[0,5 + T\left(\tau\sqrt{T}\right) + T\right] + \lambda\right\}}{2g}, \quad (7)$$

where $T = 1 - f_p$; $\varepsilon_{\mathrm{f}} = \frac{1}{X_0^2} - 1$; χ_0 is coefficient of air flow rate from the holes; ε_0 is coefficient of filling the cross-section of the holes in HF; τ is coefficient of taking into account the shape of the inlet edge of the holes and the conditions of air flow through them; λ is coefficient of hydraulic friction over the entire depth of the hole; g is gravitational acceleration (m/s^2); f_p - coefficient of perforation of HF (m^2).

Calculations by formula (7) for the optimal working conditions of CR (T_{CR} =22°C, φ = 40%, v = 0.45 m/s) show that for obtaining ΔP_{HF} more than 20 pa, i.e. for the condition when ΔP_{CR} is more than ΔP_{AR} or ΔP_{CR} is more than ΔP_{UHFS}, the value of f_p must be greater or equal to 0.25.

It is advisable to evaluate the aerodynamic mode of RCC with using the total pressure drop of the system:

$$P_{RCC} = P_{in} - P_{fin}, \quad (8)$$

where P_{in} and P_{fin} are the initial (before replacing the filters) and final (after replacing the filters) pressure (pa).

And air consumption differences:

$$\Delta Q = Q_{in} - Q_{fin}, \quad (9)$$

where Q_{in} and Q_{fin} are the initial (before replacing the filters) and final (after replacing the filters) air consumptions (m^3/h).

The obtained analytical dependences allow determining the values of pressure loss in the main elements of RCC (Fig. 4). The validity of using the obtained formulas for evaluating the flow aerodynamic properties is confirmed by instrumental monitoring of the pressure in the air purification system for many years.

It should be noted that at a certain critical air consumption Q_{cr}, the pressure of P_{CR} approaches the value of P_{AR}, while ΔP_{HF} disappears, which is unacceptable. This method can be recommended for studying the parameters of the technological microclimate in CR and analyzing the energy efficiency of ACFS.

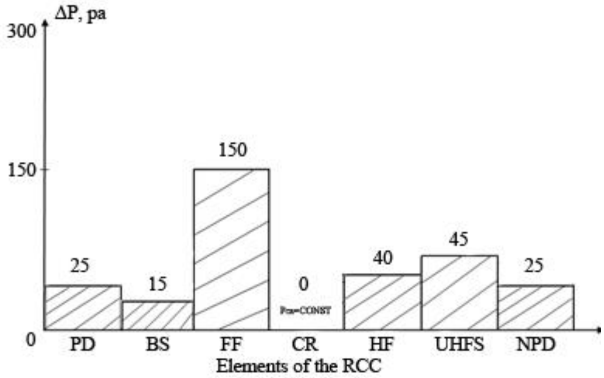

Fig. 4. Diagram of pressure loss by RCC in CR

III. CONCLUSION

Using the principles of elementarism, consistency, hierarchy and formalization of the system approach, structural and objective model for providing a given class of clean rooms in microelectronics is developed, covering the entire set of the reasons and consequences of air preparation processes.

An experimental and analytical calculation method is proposed for estimating the dynamics of air pressure changes in the main elements of RCC in ACFS of CR. It is shown that to provide the specified parameters of the technological microclimate in CR having class 5 ISO (air temperature 22 °C, humidity 42 %, air rate 0.45 m/s), which allows to obtain ΔP_{HF} more than 20 pa, i.e. to realize the condition of P_{CR} more than P_{AR} or P_{CR} more than P_{UHFS}, it is necessary to have f_p greater or equal to 0.27. It is found that as the final filters are saturated with dust, their hydraulic resistance increases, the air rate and its air consumption decrease, and at a certain (critical) air consumption G_{cr}, the pressure P_{CR} approaches to P_{AR}, and the difference ΔP_{HF} disappears, which is unacceptable.

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