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CLEAN ROOM SYSTEM TECHNOLOGY IN FUJI ELECTRIC

Soichi Yashima

1 INTRODUCTION

The introduction of a clean room (hereinafter abbreviated to CR), to be more descriptive, the efforts to suppress and control dust and fine particle in the air for room air purification and to improve the manufacturing efficiency began the last half of 1960 in our country mainly from the precise machine assembly line.

Thereafter, the introduction of CRs was expanded to the electronic industries centered around semiconductors, pharmaceutical industries, food industries and to the medical fields, and now, the CRs have been widely applied to various purposes as a common basic technology which supports the modern growing industries for new concepts such as LSI, fine mechanical, fine chemical and biotechnology.

On the other hand, Fuji Electric has made various developments for applications of static electricity for many years, and using the electric dust collecting technologies, Fuji Electric has manufactured various products related to the CR responding to the customer's needs. Further, since several years ago, Fuji Electric has treated the CR as a system technology, and by concentrating the group power, Fuji Electric has made the total engineering covering the entire range from planning to design, execution of work and provision of operating knowhow. As of this date, Fuji Electric has already delivered the system to about 100 places of various industrial fields being centered around the semi-conductor industries. This time, based on these accomplishments, special issue is made for the CR. The description covers the wide range from the system to hardware, experiment and study, and a number of experiences

Table 1 Cleanliness class of CR (BCR) (Number of particles/1)

Density \ Size of particle		Total particle diameter	0.5 μm or larger	6.5 μm or larger
Class	100		3.5	
Stratosphere	4 km	5,200	7	
	1 km	35,000	20	
Class	10,000		350	2.3
Ocean		210,000	2,500	28
Class	100,000		3,500	28
Continent		17,700,000	30,000	28
City	Non-polluted		177,000	
	Polluted		350,000	69
Labor sanitation			1,770,000	

Table 2 Density of dust within the air

Class	Fine particle (CR)			Bio fine particle (BCR)		Pressure (mmAq)	Temperature (°C)	Humidity (%)	Air flow	Brightness (lx)
	Size (μm)	(Number of pieces/cu.ft)	(Number of pieces/1)	Floating value (Number of pieces/1)	Precipitation value (Number of pieces/ sq.m week)				Number of ventilations	
100	0.5 or more	100 or less	3.5 or less	0.0035 or less	12,900 or less					
10,000	0.5 or more 5.0 or more	10,000 or less 65 or less	350 or less 2.0 or less	0.0176 or less	64,600 or less	1.3 or more	Designated value	45 ~ 40	Laminar flow 0.45 m/s ±0.1 m/s Turbulent flow 28 or more/h	1,080 ~ 1,620
100,000	0.5 or more 5.0 or more	100,000 or less 700 or less	3,500 or less 25 or less	0.0884 or less	323,000 or less					

(Note) CR: US Federal Standard N209b BCR: NASA Standard NH33340.2

have been accumulated. Those of company confidential of the customers are, however, omitted or introduced generally in the description.

2 MEANING OF AIR PURIFICATION AND POSITIONING OF CR

Normally, existence of thousands of floating fine particles in the air is out of our concious. However, we have experienced to see them by seeing lights despersed from fine particles in the air by the rising sun or by motion picture prospectors in theaters.

As for cleanliness of CRs, the levels are classified into 100, 10,000, and 100,000 as described later.

Referring to *Table 1*, it can be understood that the class of space in a city is 100,000 which is 50 to 100 times as great as that in a CR, and the class 100 of CR is equivalent to that in the stratosphere in 4km altitude or higher. It may also be necessary to know that the dust generated from a human body which considerably affects cleanliness reaches one to ten million pieces per minute through normal motions. With considerations given to the general evnironment and various dust generating sources, very precise devises and considerations are required by the CR technology, and the air purifying technology which was simply one of the air conditioning technologies has been changed to a

Table 3 Cleanliness required at various industries

Industry classification	Application \ Cleanliness	Class 100	1,000	10,000	100,000
Semi-conductor industry	Crystal refining	—			
	Diffusion	—			
	Etching process	—			
	Positioning	—			
	Surface treatment	—			
	Metal vaporisation	—			
	Assembly/test	—	—	—	—
	Raw material		—		
	Grinding/polishing	—			
	Packaging				—
	Semi-completed product storage			—	
Optical machine/equipment	Lens polishing process	—	—	—	
	Scale engraving	—			
	Machining and seembling camera for medical applications	—			
	Lens laminating process	—			
	Manufacturing and drying film			—	
	Microfilm, development, drying	—	—		
	Assembly	—	—	—	
	Painting			—	—
	Test and inspection			—	—
Watch and precise machines	Electronic watch, parts, assembly	—			
	Machining and assembling parts for rocket	—			
	Artificial satellite controller	—			
	Highly reliable parts and devices	—	—		
	Miniature bearing	—			
	Ordinary bearing				—
	Assembly and inspection	—	—	—	—
Electronic computer	Magnetic drum	—			
	Magnetic tape	—			
	Machining, assembling, testing and inspection	—	—	—	—
Electronic machine and equipment/ Electric measuring instruments	CRT	—	—		
	Highly reliable tube	—			
	Video controller	—			
	PCB			—	
	Small relay	—	—		
	Precise electric instruments	—	—	—	
	Parts, machining, assembly and inspection	—	—	—	—
Pharmaceutical products, Medecine, Hospital	Pharmaceutical manufacturing process	—	—	—	—
	Injection, sealing into tube	—			
	Storing blood, Ringer's solution, vaccine	—	—		
	Aseptic surgery room	—			
	Ordinary surfery room			—	—
	Recovery room ICU, CCU			—	—
	Aseptic room	—	—	—	
	Rooms for born babies and immature babies			—	—
	Aseptic room	—			
	Storing tools and instrument for surgery	—			
	Aseptic animal experiment	—			
	Bacteriological experiments	—			
	Drug room	—	—	—	
	Ordinary sick-rooms			—	—
	Medical examination and treatment room			—	—
Food and brewery	Mil, wine and acidophilus beverage	—			
	Bottling and capping beverages	—	—	—	
	Milk product and confection packing process				—
	Sliced and packed ham manufacturing	—	—		
	Seeding mashrooms	—	—		
	Meat treatment		—	—	—

system technology which organically consists of number of technologies.

The class used as CR evaluation standard was developed by the technologies in the United States of America first, and orginary, it is expressed by number of fine particles in size of 0.5 μm or larger within 1 cu.ft. as shown in *Table 2*.

In our country, however, under the same idea as three ranks shown in the *Table 2*, class 1000 is used, or classes 300,000 and 500,000 to be called "dust-proof room" or concepts of class 10 and 1 having higher purity may also be used. Further, for size of objective particle, in many cases, 0.3 μm is used as the standard rather than 0.5 μm, and recently, even 0.1 μm is used. At any cases, as described later, the standard particle size has an extremely important meaning, and it has been examined very carefully.

The CR classified as described above is selected in response to the application. *Table 3* shows standards of cleanliness generally applied at various industries. Manufacturing processes are advanced daily, particularly in the field of LSI, and it is obvious that the required cleanliness is not absolute, from the fact that new classes have been introduced. And, required cleanliness must be carefully examined for each case individually.

3 HOW TO UNDERSTAND CR SYSTEM TECHNOLOGY

3.1 From hardware to system, and again from system to hardware

As long as air purification is concerned, Fuji Electric has manufactured since many years ago an electric air purifier (*Fig. 1*) which is built in the air handling unit for build ings, package type filter and power supply equipment of dust collector for industrial use. Thereafter, in response to the social needs, Fuji Electric has led the industries as a hardware supplier of CR related machines and equipment such as clean bench, clean booth, air shower and pass box by applying the above mentioned air purifying technologies. Adding various system requirements and special conditions to these hardwares, Fuji Electric has emphasized the systemization, and since 1976, many CR systems have been delivered to the customers and accepted by them favorably.

Further, recently, position of hardware has increased again in the CR systems because of the trends to reduce construction time, space, energy and size of particles, and Fuji Electric has developed new hardwares such as a clean unit, thermal clean bench, thermal clean booth and thermal clean cube.

In other words, Fuji Electric is proceeding the developments by mutually compensating the hardware and system. This fact is considered extremely effective as a super high clean space of class 10 has been required and such a concept as clean tunnel or clean tube is being presently generated.

3.2 Total engineering

In comparison with ordinary buildings, space required in wiring and piping for power supply, air conditioning, water supply and drainage for CRs are greater. In addition, various special utilities required for the manufacturing processes are added, causing height of one floor of the building to reach 6 to 7 meters or area of the machine room for the CR often becomes equivalent to the area of CR.

In other words, within a CR, various machines and equipment (*Table 4*) are concentrated tightly. Therefore, it makes more complicated to handle them by type of each machine or equipment, and in many cases, unnecessary extra space must be provided. Moreover, essentially, relationships between air flow and various equipment within the room, water purifier/chemical solution and draining, special gas and air conditioner/exhaust system and selection of interior finishing material and cleanliness must be examined mutually. At the same time, to operate the CR, such a large energy as 10 to 30 times as great as an ordinary building is required, and for this reason, the design must be proceeded not only based on the initial investment (primary construction cost) but also on the running cost.

In this respect, Fuji Electric is handling a CR as one of

Fig. 1 Electric type air purifier (Model WLL-H-L)

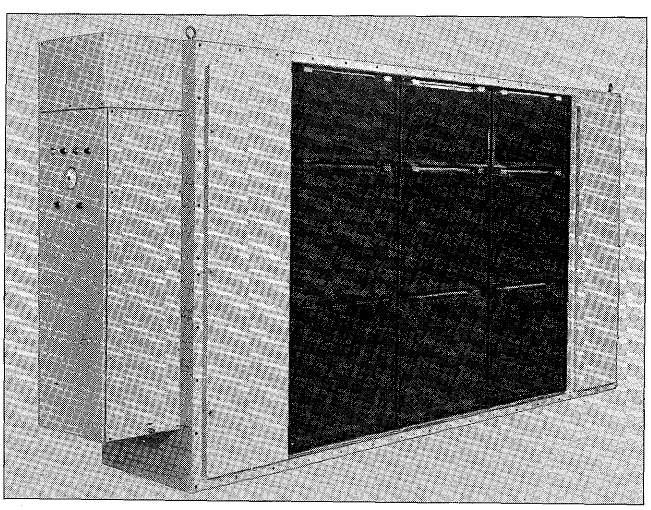
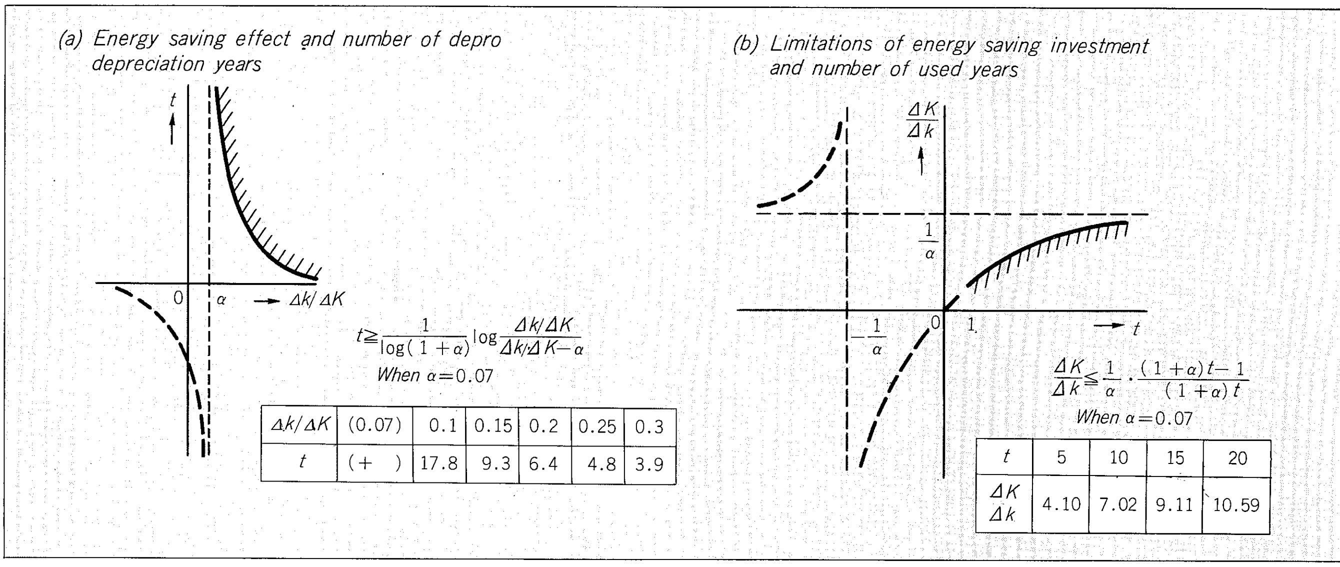


Table 4 Various equipment related to CR (Example)

Accessorial equipment for building	Accessorial equipment for manufacturing	Others
Air conditioning system	Water purifier	Production management system
Electric equipment	Special gas equipment	central control system
Sanitation/water supply/drainage equipment	Industrial water drainage/treatment equipment	⋮
Interior finishing equipment	Industrial air exhaust/treatment equipment	⋮
Security/electronic equipment	⋮	⋮

Fig. 2 **Limitations of investment and energy saving effect**



Δk/ΔK	(0.07)	0.1	0.15	0.2	0.25	0.3
t	(+)	17.8	9.3	6.4	4.8	3.9

t	5	10	15	20
ΔK/Δk	4.10	7.02	9.11	10.59

the total engineerings for both the contents and time system.

3.3 Energy saving of CR

When planning a construction of CR and the reference for judging the value can be placed on a long view point, such an idea as "Working hard first and enjoying afterward" could be permitted economically. Now, when annual reduction of the running cost (Δk) can be made by increase of the construction cost (ΔK), the following equation can be established for depreciation by compound interest method.

$$\Delta K(1+\alpha)^t \leqq \Delta k \left\{(1+\alpha)^{t-1} + (1+\alpha)^{t-2} + \ldots\ldots + (1+\alpha) + 1\right\} \quad \ldots (1)$$

Where, α: Annual interest rate

t : Number of years elapsed

When the above equation is solved for t and $\Delta K/\Delta k$;

$$t \geqq \frac{1}{\log(1+\alpha)} \log \frac{\Delta k/\Delta K}{\Delta k/\Delta K - \alpha} \quad \ldots (2)$$

$$\frac{\Delta K}{\Delta k} \leqq \frac{1}{\alpha} \cdot \frac{(1+\alpha)^t - 1}{(1+\alpha)^t} \quad \ldots (3)$$

And, the results are graphed as shown in *Figs. 2(a)* and *(b)*. The *Fig. 2* ahows the calculated value for $\alpha = 0.07$ also. With the *Fig. 2(a)*, it can be understood that when $\Delta k/\Delta K$ (to be called investment effect rate) is not larger than the interest rate α depreciation collection cannot be made, but when it is larger than the interest rate, number of depreciation years reduces, and for example, when effect rate is 20 to 30%, number of depreciation years is 6 to 4 years.

Further, with the *Fig. 2(b)*, $\Delta K/\Delta k$ (to be called investment limit rate with number of used years t) can be found. For example, when the view point is placed in 10 years, an initial investment which is seven times as great as the running cost reduction (Δk) can be expected.

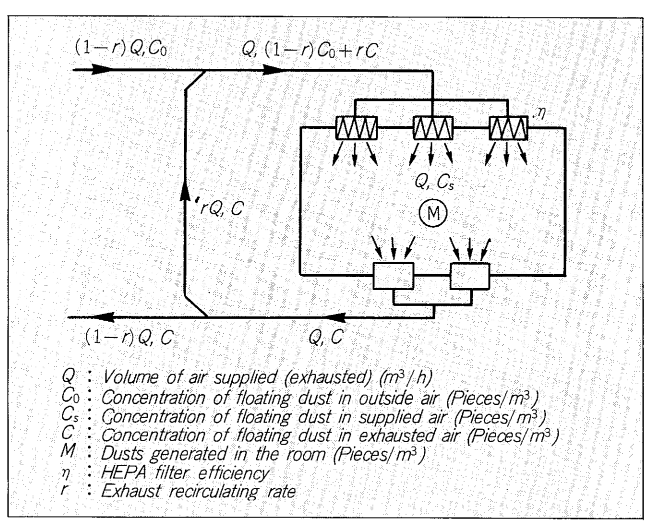
Fuji Electric is always desiring to aim at the above described target in which the viewpoint is placed far ahead because, at present, CRs are varying as a system and new methods are being tried.

4 DEVELOPMENTS OF CR SYSTEM TECHNOLOGY

4.1 Problems of cleanliness and air flow (C_s management and C management)

To understannd the presently used CR mode, the circulation system of CR which is extremely simplified as shown in *Fig. 3* is examined. Using this model, concentration of blow out (C_s) from the high efficiency particulate filter for which internal dust generation (M) is taken into considerations (hereinafter abbreviated to HEPA filter) and concentration of returned air (C) are obtained. The following equation applies.

Fig. 3 **Circulation system of CR**



$$\begin{cases} QC_s + M = QC & \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4) \\ C_s = (1-\eta)\{rC + (1-r)C_0\} & \ldots\ldots\ldots\ldots\ldots (5) \end{cases}$$

C and C_s are obtained from the above equations as follows.

$$C = \frac{(1-r)(1-\eta)}{1-r(1-\eta)} C_0 + \frac{1}{1-r(1-\eta)} \cdot \frac{M}{Q}$$

$$\fallingdotseq (1-r)(1-\eta)C_0 + \frac{M}{Q} \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$C_s = \frac{(1-r)(1-\eta)}{1-r(1-\eta)} C_0 + \frac{r(1-\eta)}{1-r(1-\eta)} \cdot \frac{M}{Q}$$

$$\fallingdotseq (1-r)(1-\eta)C_0 + r(1-\eta) \cdot \frac{M}{Q} \ldots\ldots\ldots (7)$$

(where, it has been assumed as $r(1-\eta) \ll 1$.)

It can be said that the equation (6) is an equation which can be physically and directly understood easily.

Now, in the present CR cleanliness calculations, those the concentration of returned air (C) of which governs the room are called turbulet flow type, and those the concentration of blow out (C_s) of which governs the room are called laminar flow type. The latter installs the clean air blow out port and intake port separately so that flows of the air within the room do not mutually interfere and dust generating source is limited to the down stream side only. Thus, this type can be easily recognized as a C_s governed type.

However, equation (6) can be applied to turbulent flow type only when internal dust generation (M) is dispersed evenly and simultaneously. In other words, it may be applied to a small room, and actually, in a large room, it is believed that a considerably large unbalance cannot be avoided. For your reference, when examining a system to be C or C_s governed type, equations (6) and (7) may be compared. The first term shows the same value, the second term shows existence or non-existence of coefficient by $r(1-\eta)$, and if $r=0.5$ and $\eta=0.9997$ are applied, it becomes $r(1-\eta) = 1.5 \times 10^{-4}$, indicating that the width could be 10,000 times as great.

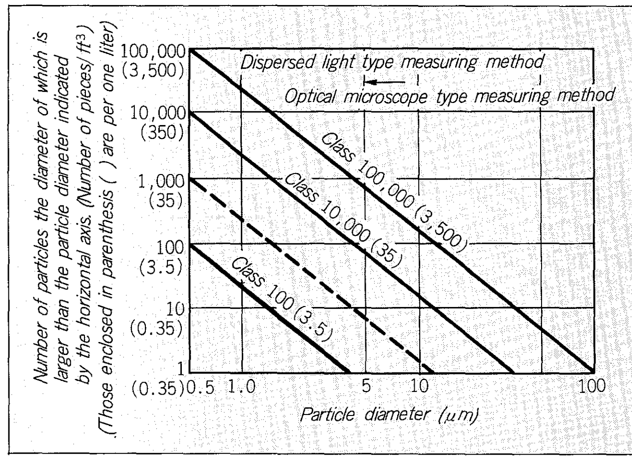
Because of these back grounds, Fuji Electric is employing not only cleanliness but also conducting experiments of cleanliness accompanied with air flow phenomenon, accumulating actual data at the actual sites, reflecting the results on the practical design and using computers, conducting air flow simulations and analysis.

4.2 0.1 μm fine grain and D^{-q} Law

Fine grain which is objective to CR presently is those of 0.5 μm or larger under the standards (Federal Standard NH109b, etc.). Actually, however, in some cases, contract condition requires 0.3 μm. Further, for the recent VLSI, manufacturing of 256 k bit MOS-RAM and study of 1 M bit integration are topics. Further, line width on a wafer must have been processed within 1 μm, and grain diameter to be eliminated in the working environment has been reduced to the range of 0.1 μm.

In this stage, whether or not the range of this extreme finness can be handled with the conventional knowledges and on the line extended from the laws is the fundamental problem. For example, grain diameter density within the air is expressed as $N = kD^{-q} \rightarrow \log N = -q \log D + \log k$ (where, k and q are constants) as shown in *Fig. 4* when number of grains and again diameter are expressed as N and D respectively, and smaller the grain diameter may be, number of grains increases. When this is extended to the range of 0.1 μm, however, in comparison with the conventional 0.5 μm, one digit higher number of fine grains must be objective, and design of equipment for such extremely fine grains cannot be realized.

Fig. 4 Particle diameter density curve (By Fed Std No. 209b)



Fortunately, for the 0.1 μm, a filter manufacturer has developed filters having one digit higher efficiency as that of the conventional HEPA filters, and also, it has been reported that the D^{-q} law has begun to saturate at 0.1 μm range.

However, still the data for handlings under various environments are insufficient, and Fuji Electric is placing the emphasis on the 0.1 μm range, including the matter of measurement.

4.3 Class 10 and yield point of product

For VLSI process, semi-conductor manufacturers are expecting a class 10 clean bench, etc. at 0.1 μm or higher. Fuji Electric, as well as other manufacturers, it employing special HEPA filters for 0.1 μm guaranteed by the filter manufacturer for such needs, and has begun the shipment after conducting precise air flow experiments. Speaking frankly, however, there are still unclear portions are remained especially in the severe evaluation on the measurement of fine grains. Fuji Electric is considering that it is necessary not only to evaluate the class of cleanliness but also to search fault causing mechanism due to fine grains in the manufacturing process for the super clean room problems.

This means that the application of the present purifying system indicated by equations (6) and (7) (Number of ventilations is increased depending on M/Q. In other words, cleaning by thinning) is limited. For example, when

(1) Class 100, Vertical streamline range of 0.5 m/s HEPA filter passing air velocity (proportions to ventilation value) is compared with;

(2) Class 10, Vertical streamline range of 5 m/s air velocity (actually, could not exist),

(2) is superior as long as nominal cleanliness is concerned. When watching motions of the fine grains, however, it contains such a contradiction as that when a horizontal plane is assumed, number of fine grains which run aginst each other is the same.

In other words, when product faults at clean environment can be explained by micro analyzations such as adhesion of fine grains to the product and collapsing rate of fine grians, yeild point of the product cannot be properly expressed by class of cleanliness only. The new streamline theory announced by Hayakawa Study team of Tokyo Institute of Technology has also suggested the above idea. Fuji Electric will take this theory up based on the actual phase and will develop it.

5 POSTSCRIPT

For CR system technologies, Fuji Electric's manner and future development were outlined. Beside CRs and as well as the CR for cleaning air from fine grains, there is a biological clean room (BCR) for pasteurizing biological grains. Since biological grains cannot be measured easily, the ranking for CR is used as is (*Table 2*). However practical BCR handling considerably differs ,from CR for semiconductors.

For details including these matters, refer to each article in this special issue. It will be our pleasure if this special issue could be a reference to the readers and readers can understand Fuji Electric's CR system technologies. At the same, we are expecting your frank opinions.

Taking this opportunity, we should like to express our deep appreciations to those customers who have employed our hardwares and systems and provided us with valuable advices as we believe that the practical CR as a total engineering can be realized only by accumulating the experience and user's evaluations.