Development of the broad-band and high response ability nano-particle concentration counter which is based on a new method.

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1)Shimadzu Corp., 2) National Traffic Safety and Environment Laboratory

Recently, people are concerned about the negative effect of nano-particles on human health. Diesel-engine vehicles are thought to be the large source of nano-particles. In response to this the regulation for nano-particles is being introduced in Europe to prevent these effects. The measurement system for this regulation has high accuracy and repeatability. But it is so complex, huge and expensive. It is difficult to adjust this measurement system to on-site measurement which has not been discussed yet. We think, there is an increasing need for the on-site measurement of nano-particles from vehicles that are being used. So National Traffic Safety and Environment Laboratory (NTSEL) has designed a novel nano-particle measurement instrument (Broadband Differential Mobility Analyzer: B-DMA) that is easy to operate and can measure the number of nano-particles with wide diameter range simultaneously. This instrument uses a similar principal to the current differential mobility analyzer (DMA). As it is well known that the DMA can't collect wide diameter range of particles simultaneously. A few DMAs can solve it. But they are still expensive and complex for the purpose that we are aiming for. The B-DMA can measure the number of accumulation mode particles and it can reject nuclei mode particles. The principle of the B-DMA is shown in Figure1.

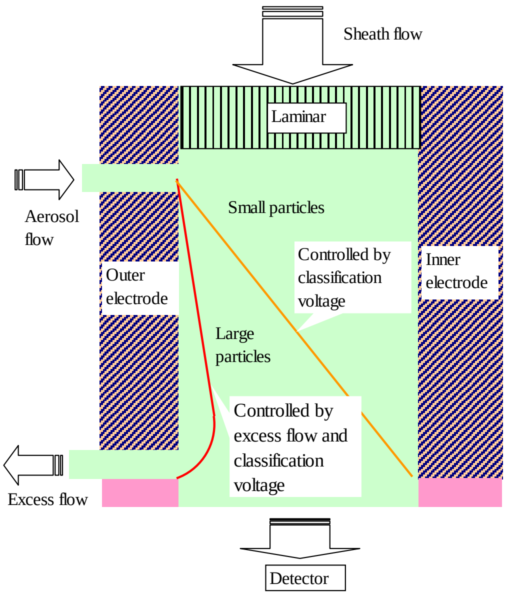

Figure1. The principle schematic of the B-DMA.

The smaller particles which dose not be measured, are trapped on the inner electrode by the van der Waals force. The larger particles which dose not be measured, are ejected by the excess flow. The small classification limit is controlled by the classification voltage under a constant sheath flow velocity. The large classification limit is controlled by the classification voltage and the excess flow velocity under a constant sheath flow velocity. The size-dependent collection rate of the B-DMA is shown in Figure 2 for 5 types of testing conditions. The lower limit of characteristic of classification is defined only by the classification voltage, free from the excess flow velocity. The upper limit of characteristic of classification is defined by both the classification voltage and the excess flow velocity. Increasing classification voltage raises collection rate under the same excess flow condition. And increasing excess flow velocity causes the collection rate to drop under the same classification voltage condition. So the B-DMA can control the upper and lower limit of the classification range independently.

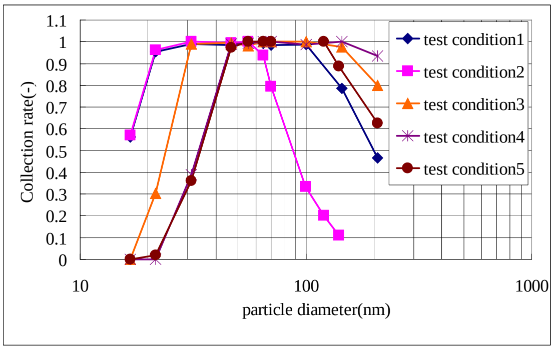

Fig.2 The size-dependent collection rate of the B-DMA. Each testing condition has 4 parameters which are Sheath flow velocity (Qc), Excess flow velocity (Qe), Aerosol flow velocity (Qa), and Classification voltage (E). Testing conditions are shown below and explained in the following order, Testing No., Symbol, Qc, Qe, Qa, E. (1, Rhombus, 60slm, 1slm, 1slm, 500V), (2, Square, 60slm, 3slm, 1slm, 500V) (3, Triangle, 60slm, 1slm, 1slm, 1000V), (4, Star, 60slm, 1slm, 1slm, 1800V) (5, Circle, 60slm, 3slm, 1slm, 1800V)

We compare with the B-DMA and the PMP measurement system for the validation exercise for the HDV. Both are set after the diesel-engine. And we run the engine as in the JE05 mode test that is one of the Japanese transient mode test standards. The B-DMA correlates to that of the PMP system and the B-DMA has same time response ability as the PMP system, even though the B-DMA is a simpler structure than the PMP system.

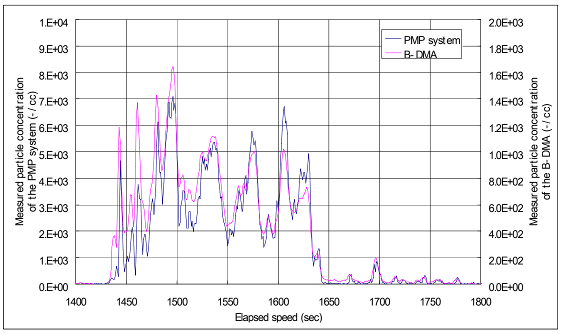

Fig.3 Measurement result of the JE05 mode test. This figure is an enlargement of a part of the JE05 mode test. Collection particle diameter range of the B-DMA is set from 30nm to 70nm and in this case collection rate of particle is set over 60% in all ranges. Engine type is diesel with the DPF and its displacement is 7684cc and it adjusts for 2005 regulation of Japan.

In conclusion,

・We develop a B-DMA that can measure the number of accumulation mode only.

・The B-DMA can control measuring particle size range by changing driving conditions. And can control the large side and small side of the range independently.

・The B-DMA has time response ability for the transient mode test.

・We can see a correlation between the PMP system and the B-DMA, but they does not correspond with exactly.

・When stricter regulations are introduced in the future, the B-DMA has the ability to adjust.

・We can still improve the accuracy of the B-DMA

Acknowledgement

NTSEL designed this B-DMA as part of the JRTT project.

JRTT : Japan Railway Construction, Transport and Technology Agency

NTSEL : National Traffic Safety and Environment Laboratory

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CONTENTS

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BACKGROUND

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Concern about the negative effect of nano-particles on human health

→ Vehicles are thought to be a large source

Limitation of mass measurement method’s Sensitivity and Suitability

→ The regulation for the number concentration of the nano-particles

Regulation for the number of nano-particles

for the vehicles that are being used

TARGET

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-Economic -Convenient -Compact	⇒	Maintenance station Onsite inspection On-board measurement
-Quick response	⇒	Transient mode test
-Wide range measurement	⇒	Total accumulation mode

PRINCIPLE OF THE CURRENT DMA

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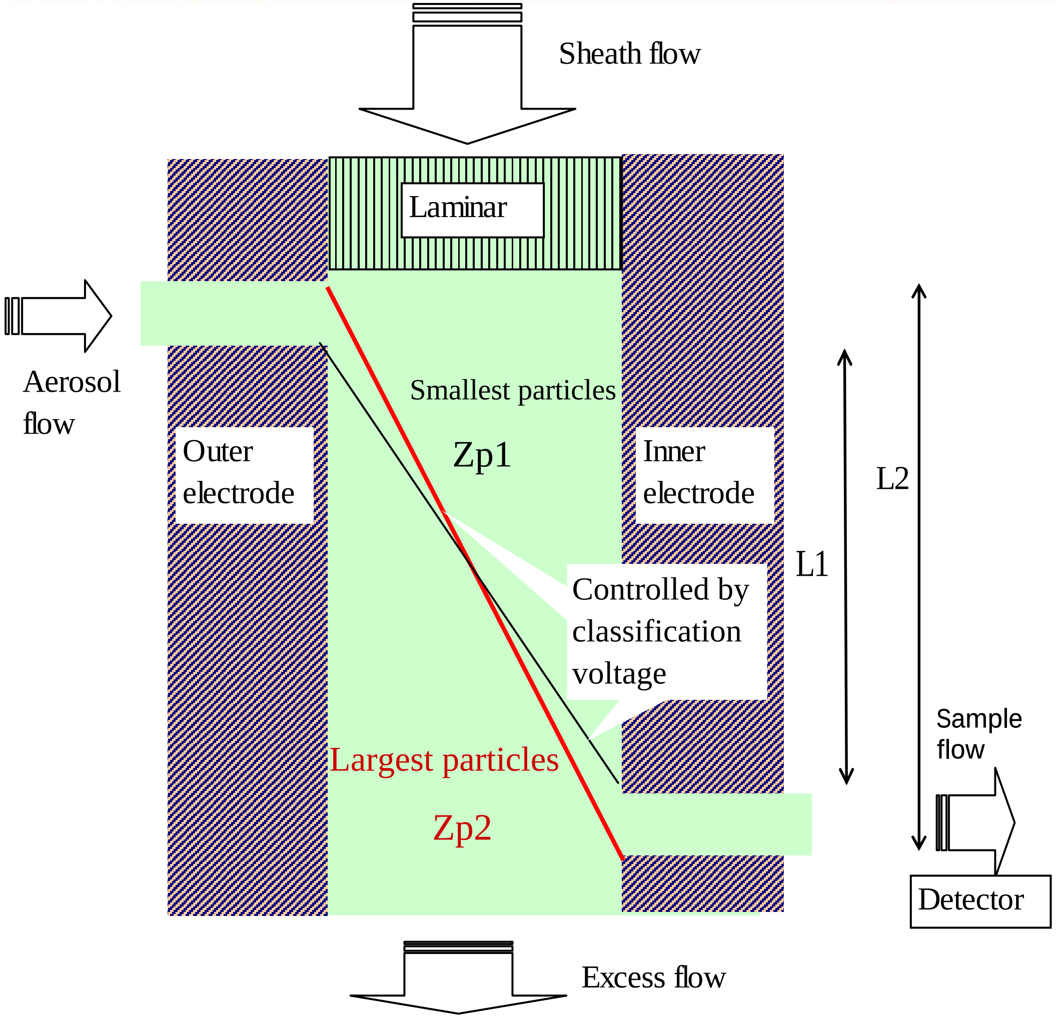


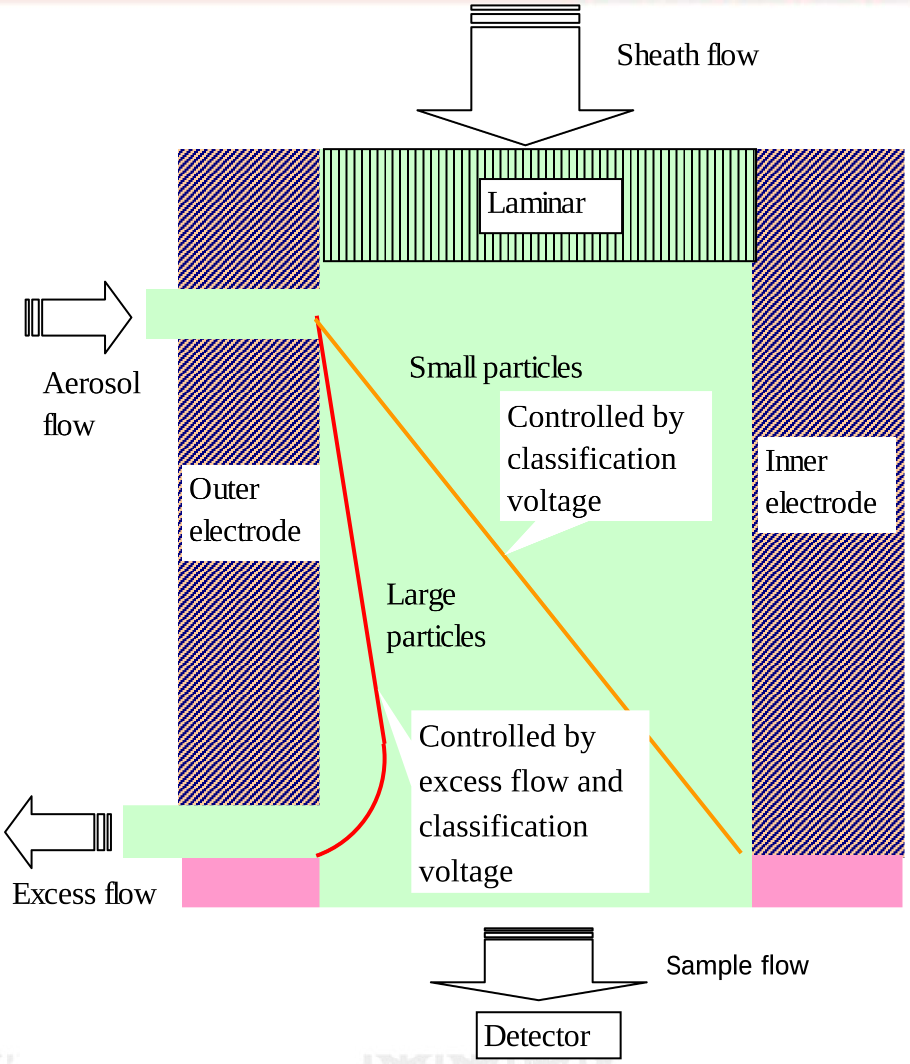
$$Zp1/Zp2=L2/L1$$

$$Zp_{(+1,30nm)}=2.4\times10^{-7}\ (m^2/V\cdot sec)$$

$$Zp_{(+1,124nm)}=1.8\times10^{-8}\ (m^2/V\cdot sec)$$

$$\frac{Zp_{(+1,124nm)}}{Zp_{(+1,30nm)}}=13.1$$

PRINCIPAL OF THE B-DMA



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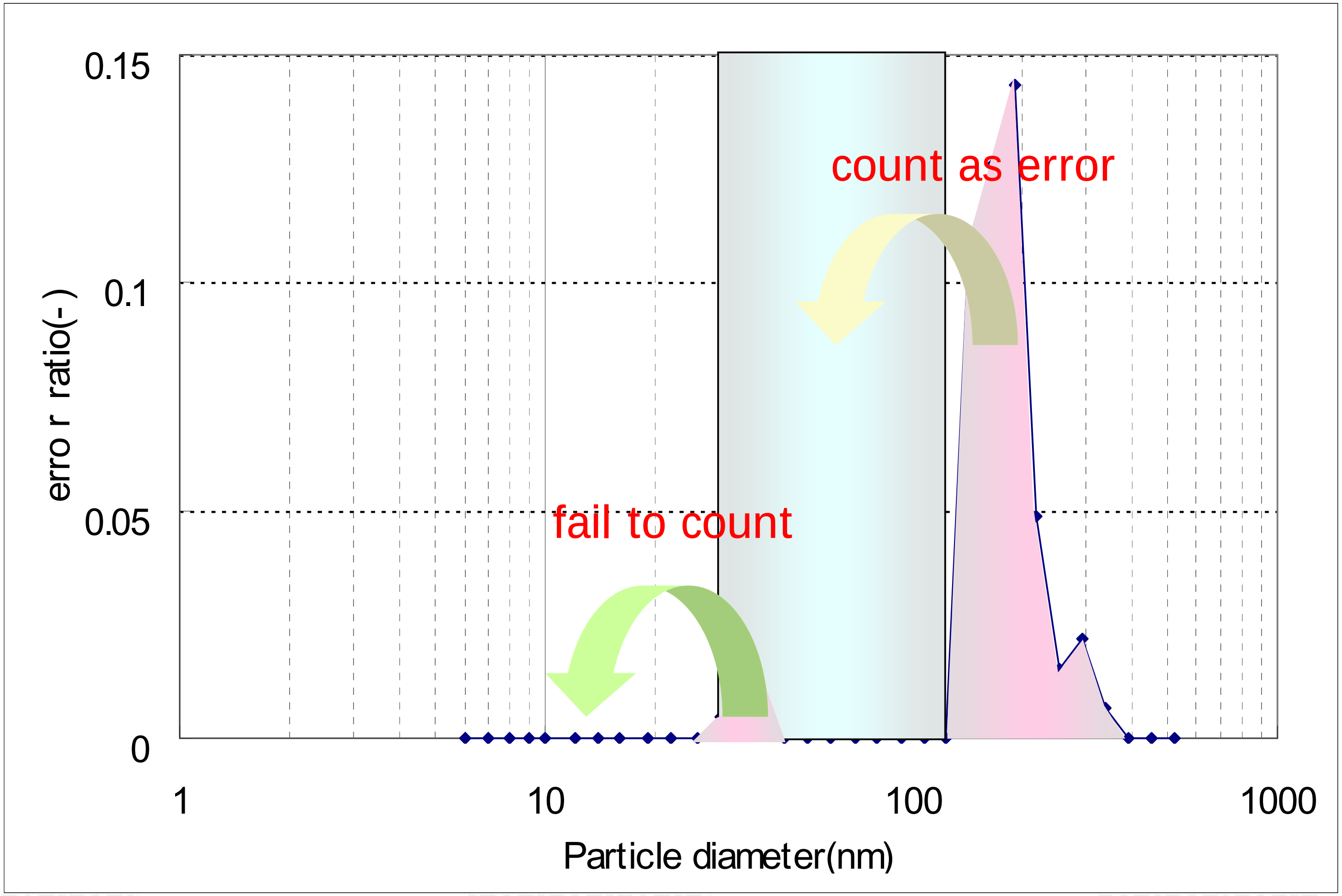
Calculated theoretical error ratio



CHARGING NUMBER FOR DATA CONVERSION

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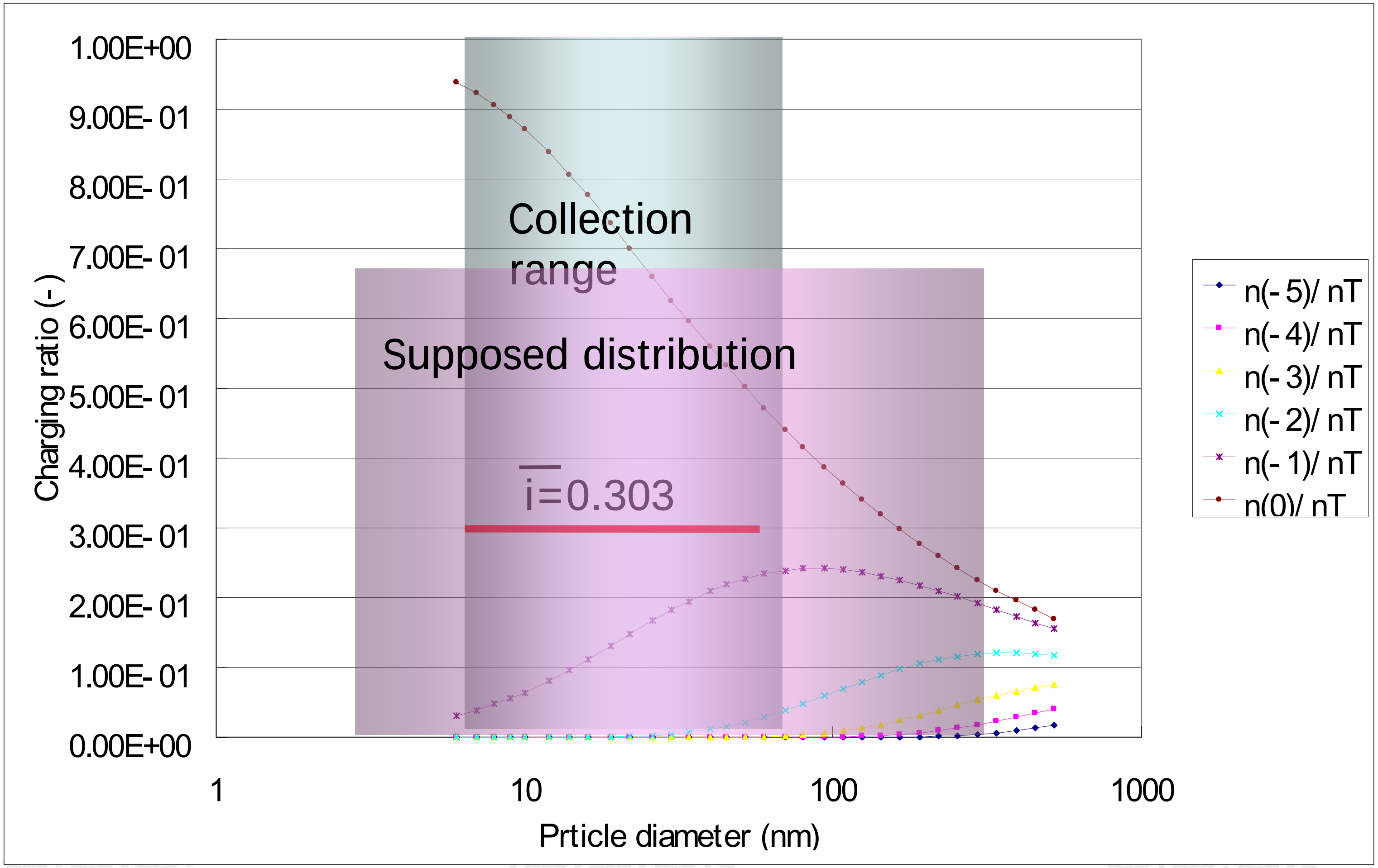
■Supposed charging number



CHARACTERISTIC OF CLASSIFICATION

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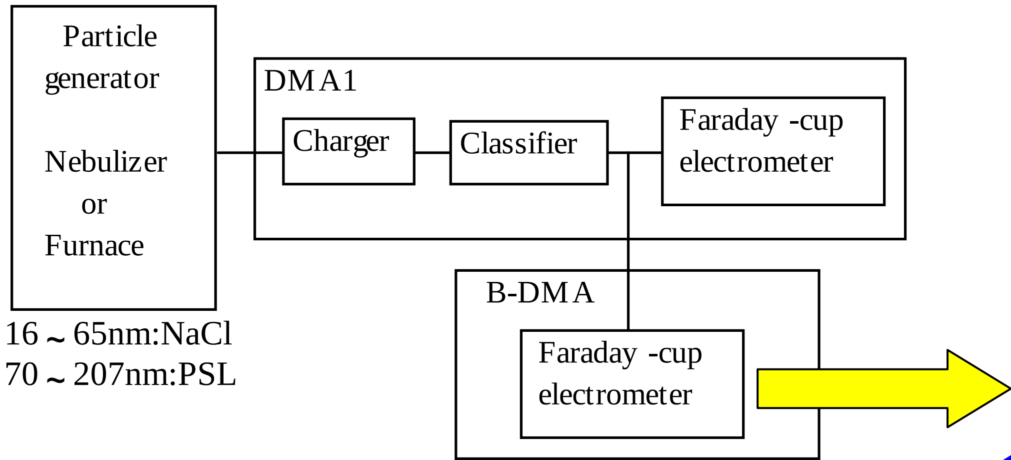
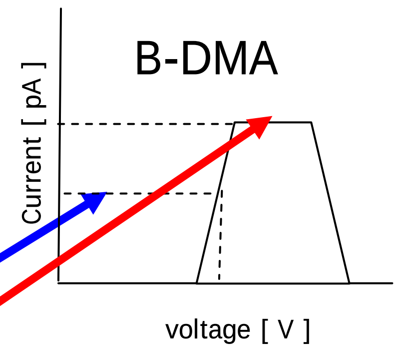
■ Measurement set-up for characteristic of classification





$$\textbf{Collection rate [-]} = \frac{\textbf{Detected current [pA]}}{\textbf{Peak current [pA]}}$$

Nebulizer	Shimadzu. Co.,	UAG-1
Furnace	Shimadzu. Co.,	SSM-5000A
DMA1	Wyckoff. Co., Ltd	DM-2A
Carger		^{241}Am

CHARACTERISTIC OF CLASSIFICATION

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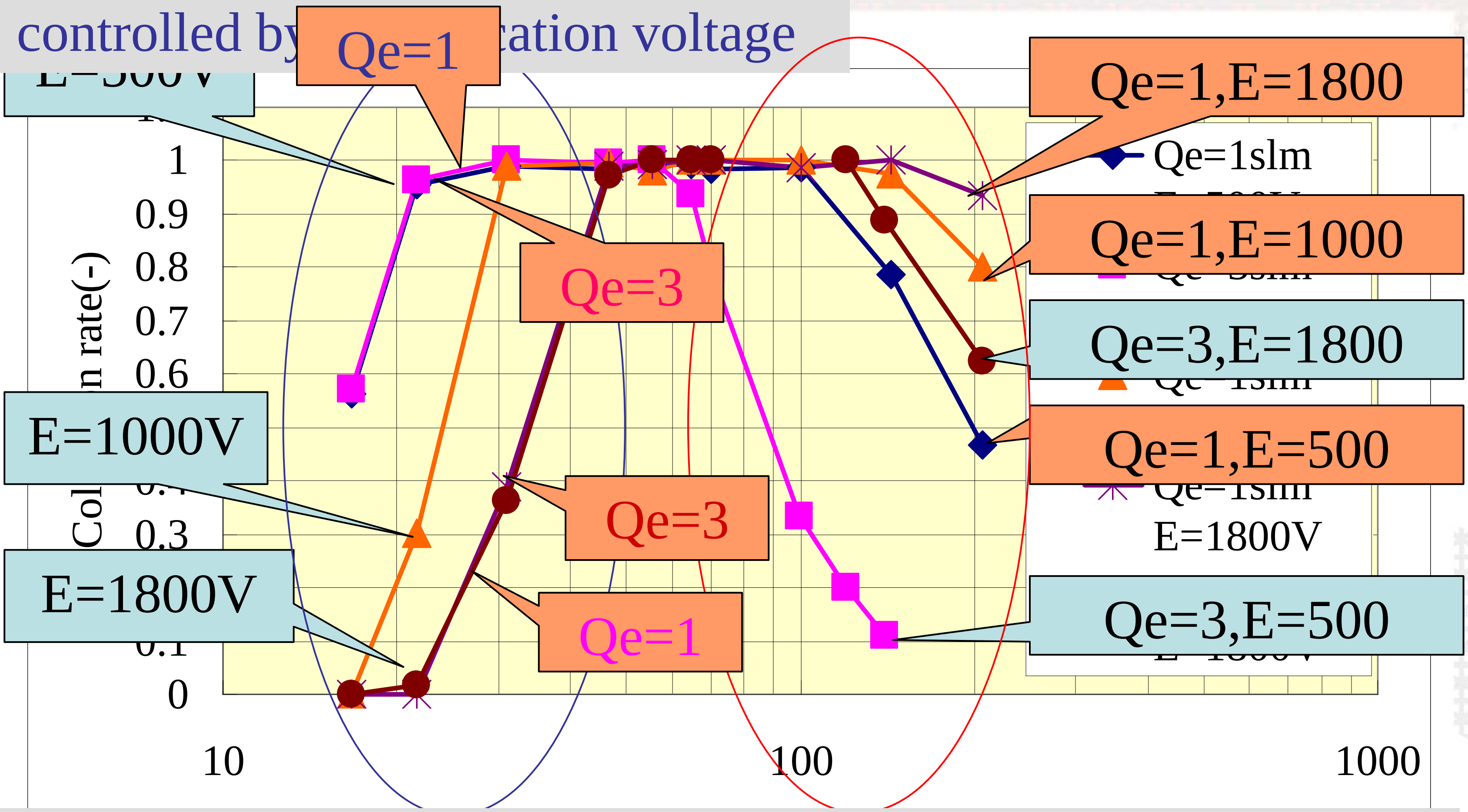
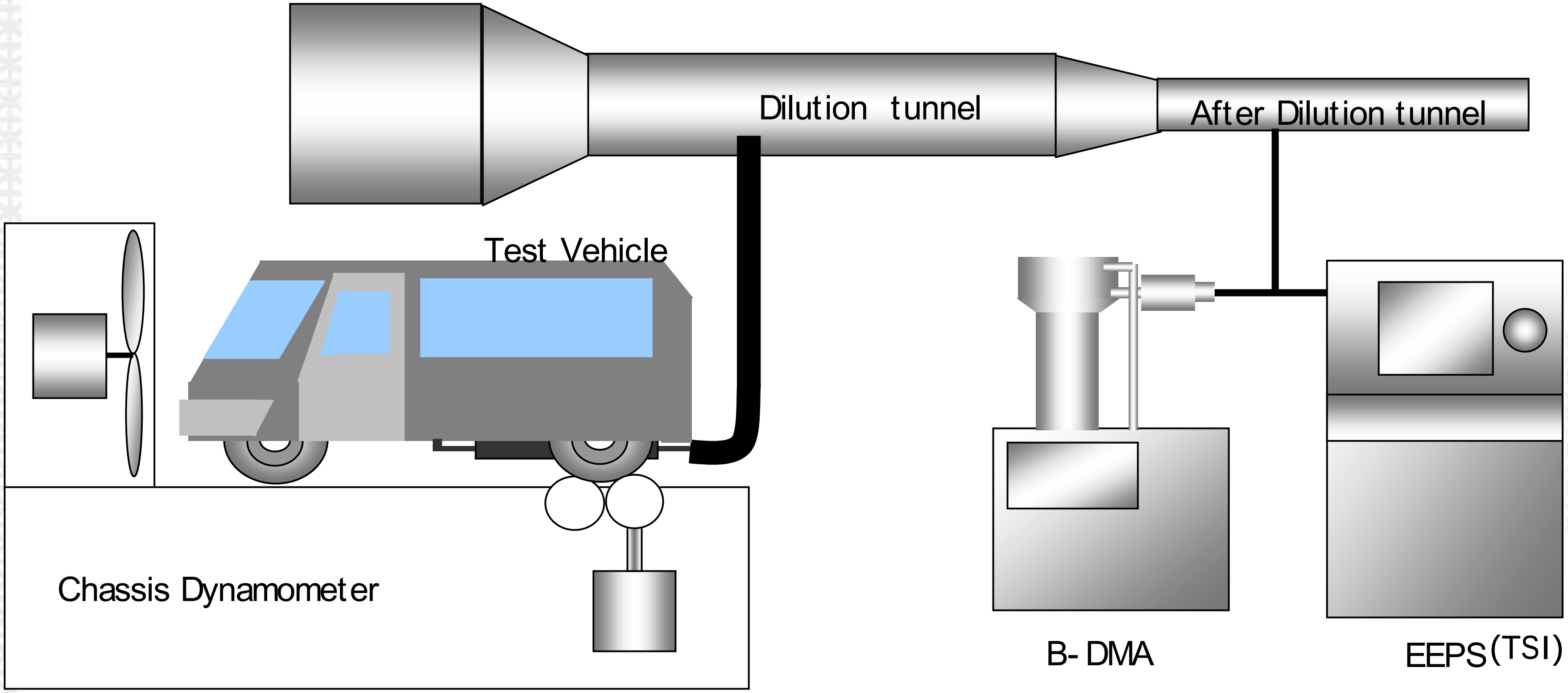
controlled by classification voltage



controlled by classification voltage and excess flow velocity

NEDC COLD START TEST

- Experimental setup for the response characteristic for NECD cold start test



NEDC COLD START TEST

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Measurement conditions

Driving pattern		NEDC cold (New European Driving Cycle)
Diluter flow		$10m^3$/min
Charger		Bipolar
Test condition of B-DMA	Sheath flow	24slm
	Excess flow	3slm
	Aerosol flow	3slm
	Classification voltage	+620V
	Collection range	30-70nm *1)
Type of vehicle	Engine type	Diesel
	Displacement	1.998L
	Manufactured	Dec.2003 ~
	Satisfied regulation	New short-term target

RESULT OF NEDC COLD START TEST

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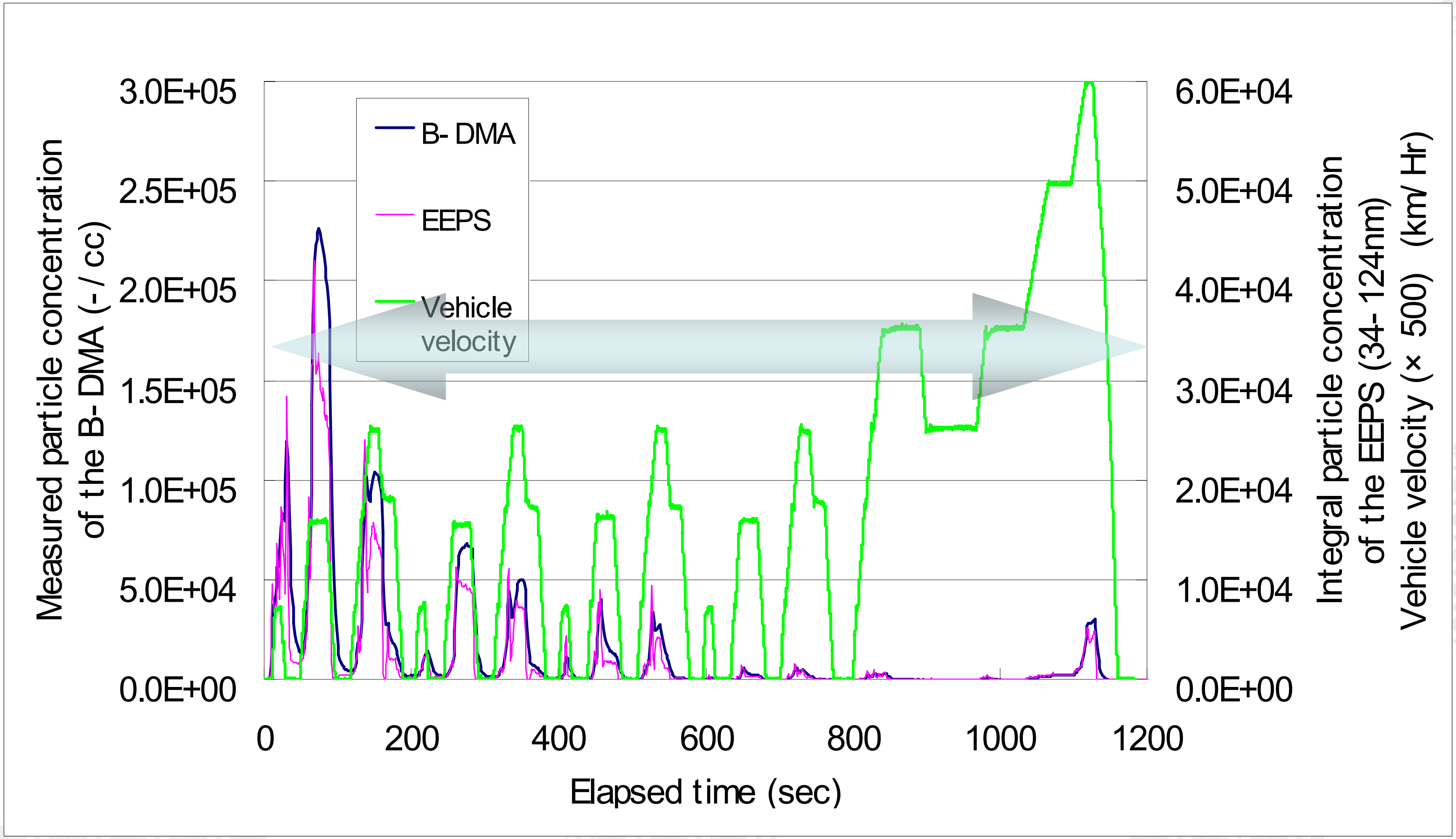

JE05 MODE TEST

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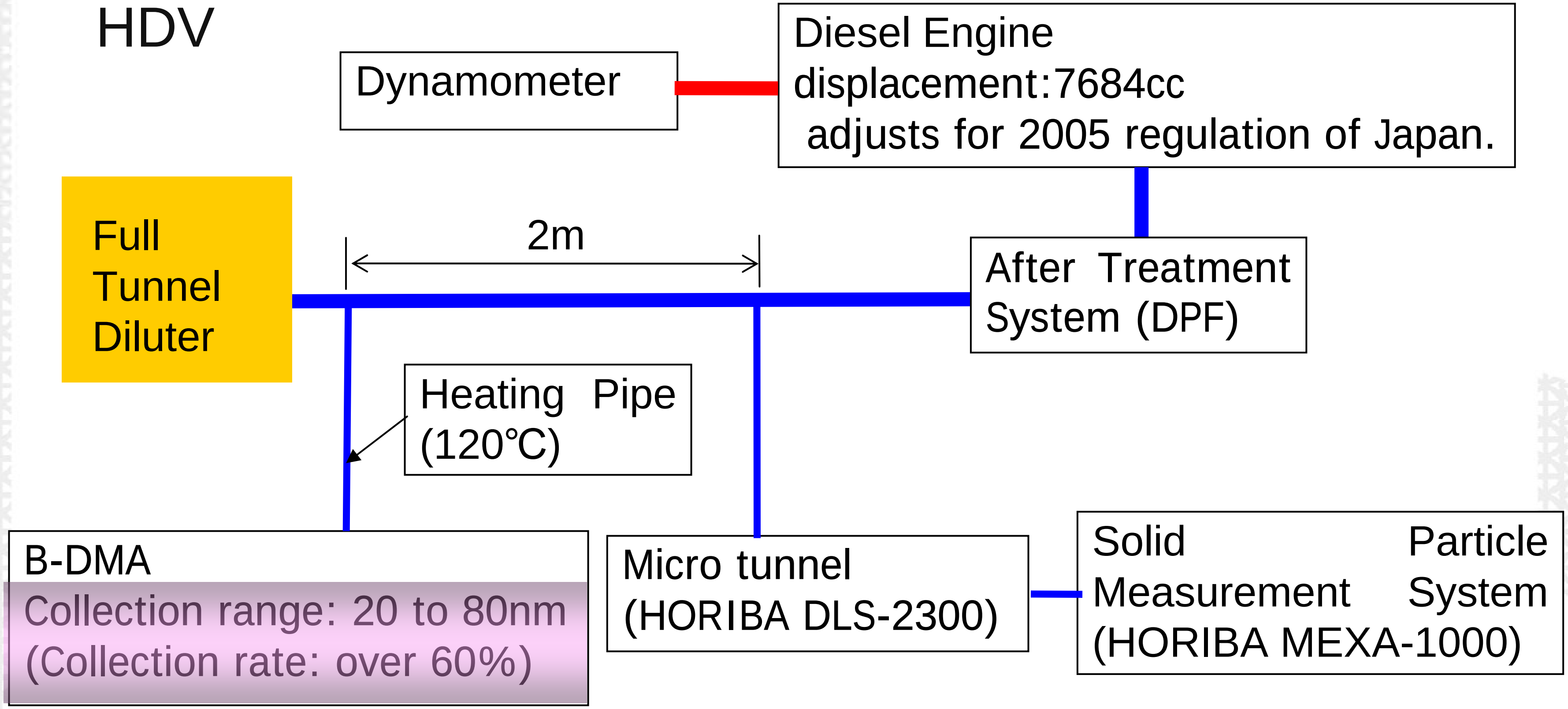
- Experimental setup for the comparison test with the PMP measurement system for the validation exercise for the HDV



RESALT OF JE05 MODE TEST

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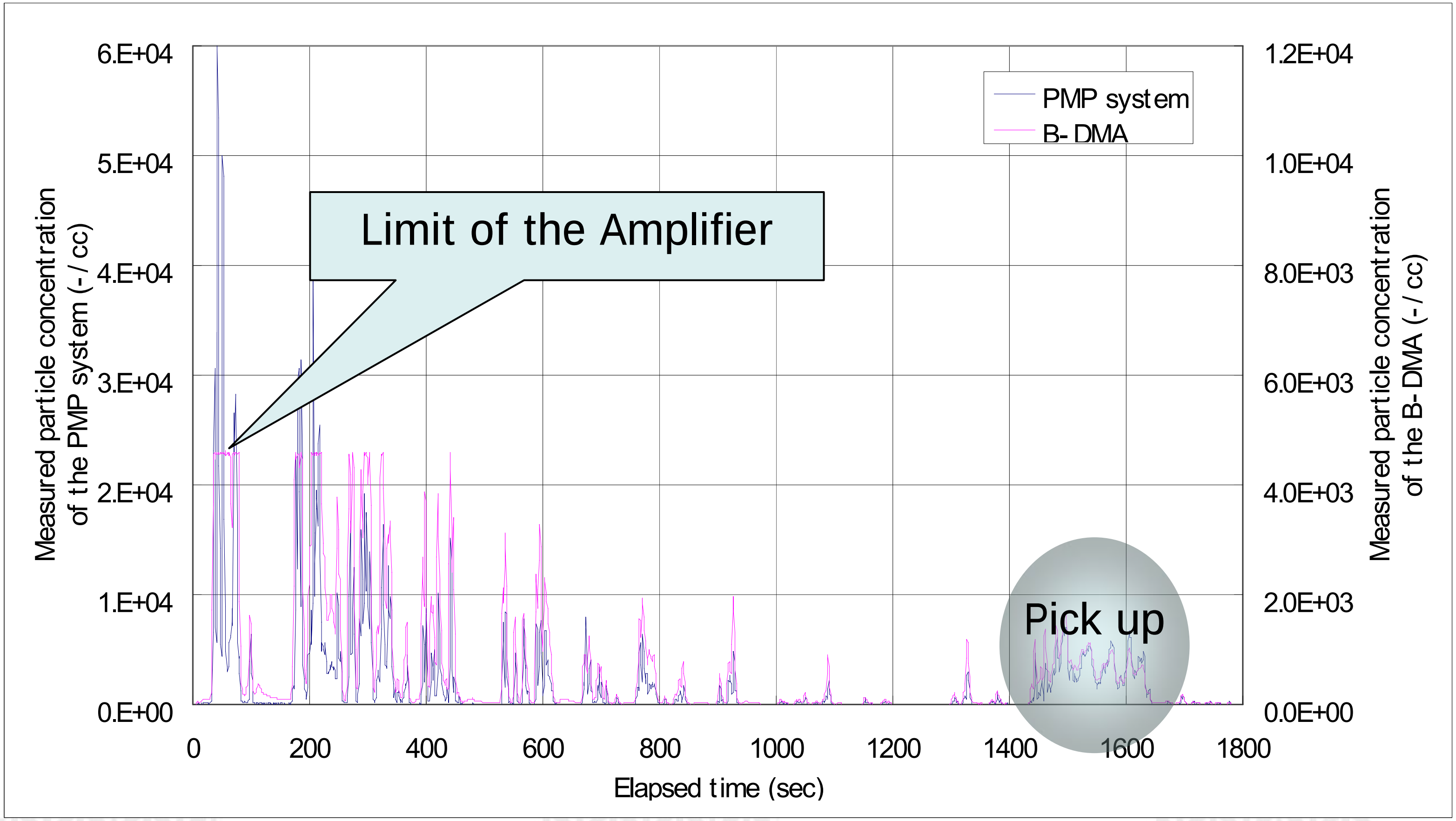
■Response characteristics of the B-DMA and the PMP system for the JE05 mode test



COMPARED WITH PMP SYSTEM

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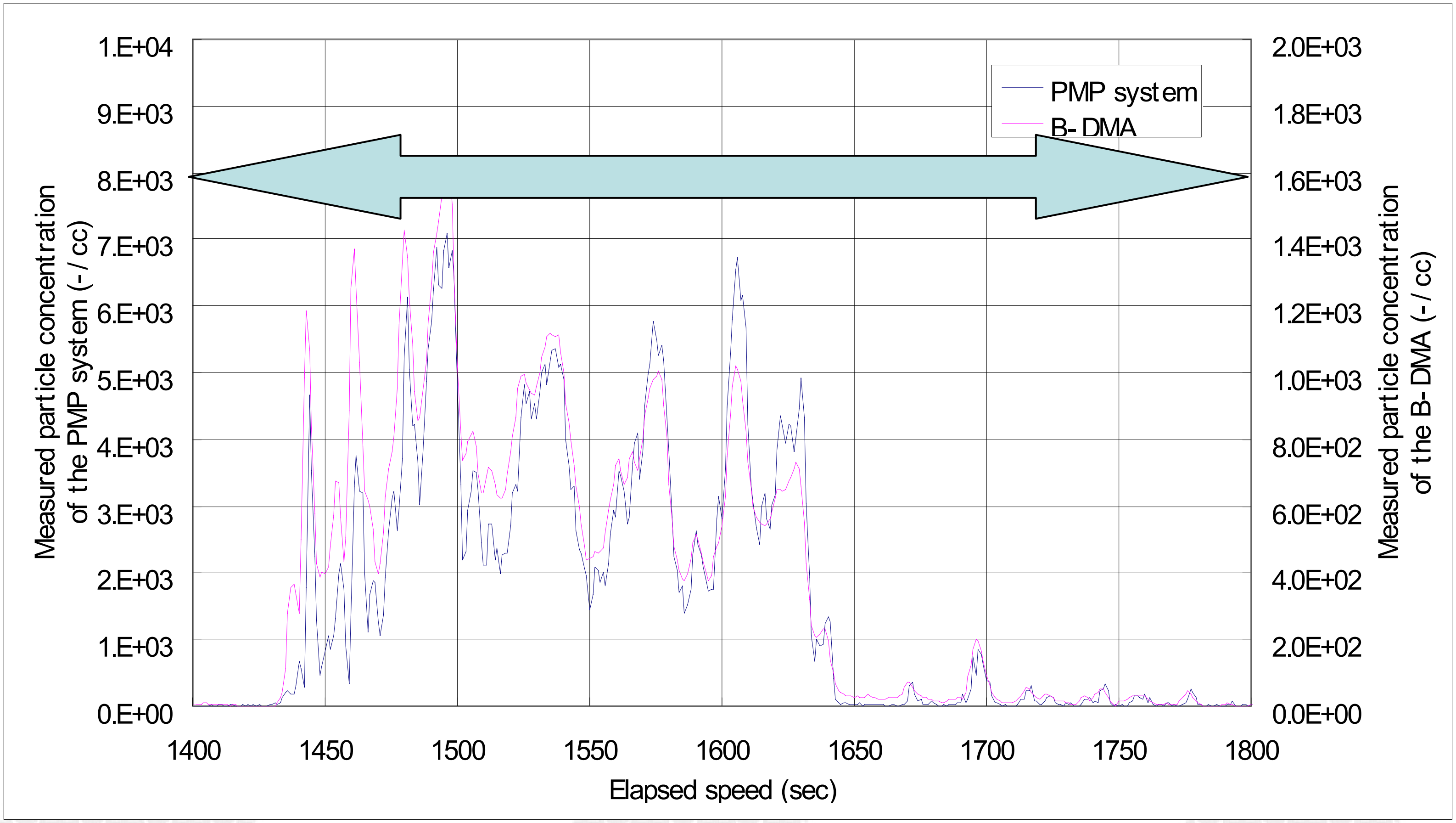
- Response characteristic of the B-DMA and the PMP system for the JE05 mode test (Enlarged part)



CONCLUSION

- We develop a B-DMA that can measure the number of accumulation mode only.
- The B-DMA can control measuring particle size range by changing driving conditions. And can control the large side and small side of the range independently.
- The B-DMA has time response ability for the transient mode test.
- We can see a correlation between the PMP system and the B-DMA, but they does not correspond with exactly.
- When stricter regulations are introduced in the future, the B-DMA has the ability to adjust.
- We can still improve the accuracy of the B-DMA

ACKNOWLEDGMENT

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NUMERICAL SIMULATION

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Simulation condition

Radius of inner electrode	25mm
Radius of outer electrode	33mm
Slit width	0.5mm
Slit distance	100mm
Classification voltage	1366.9V
Sheath flow	100L/min
Aerosol flow	1L/min

RESULT OF NUMERICAL SIMULATION

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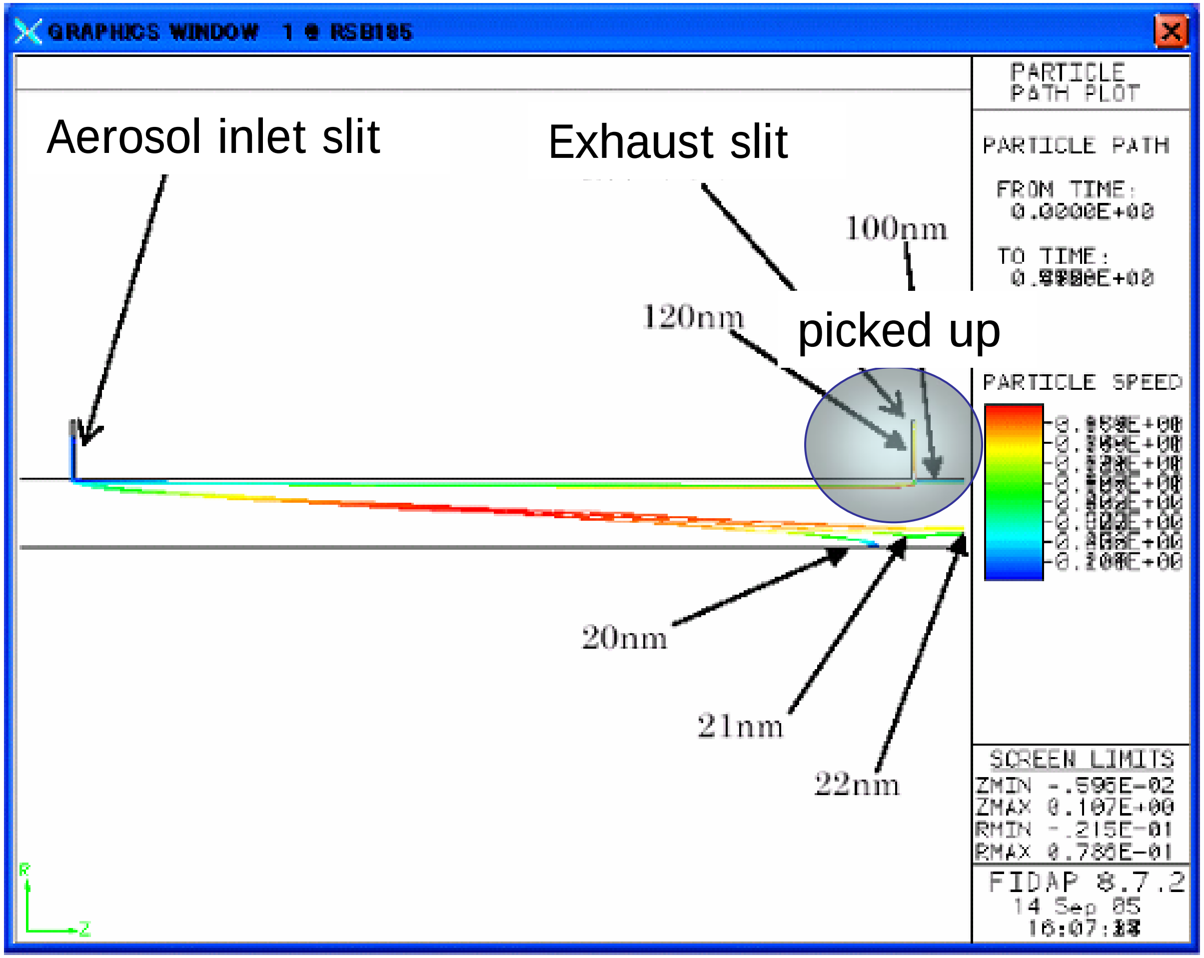

RESULT OF NUMERICAL SIMULATION

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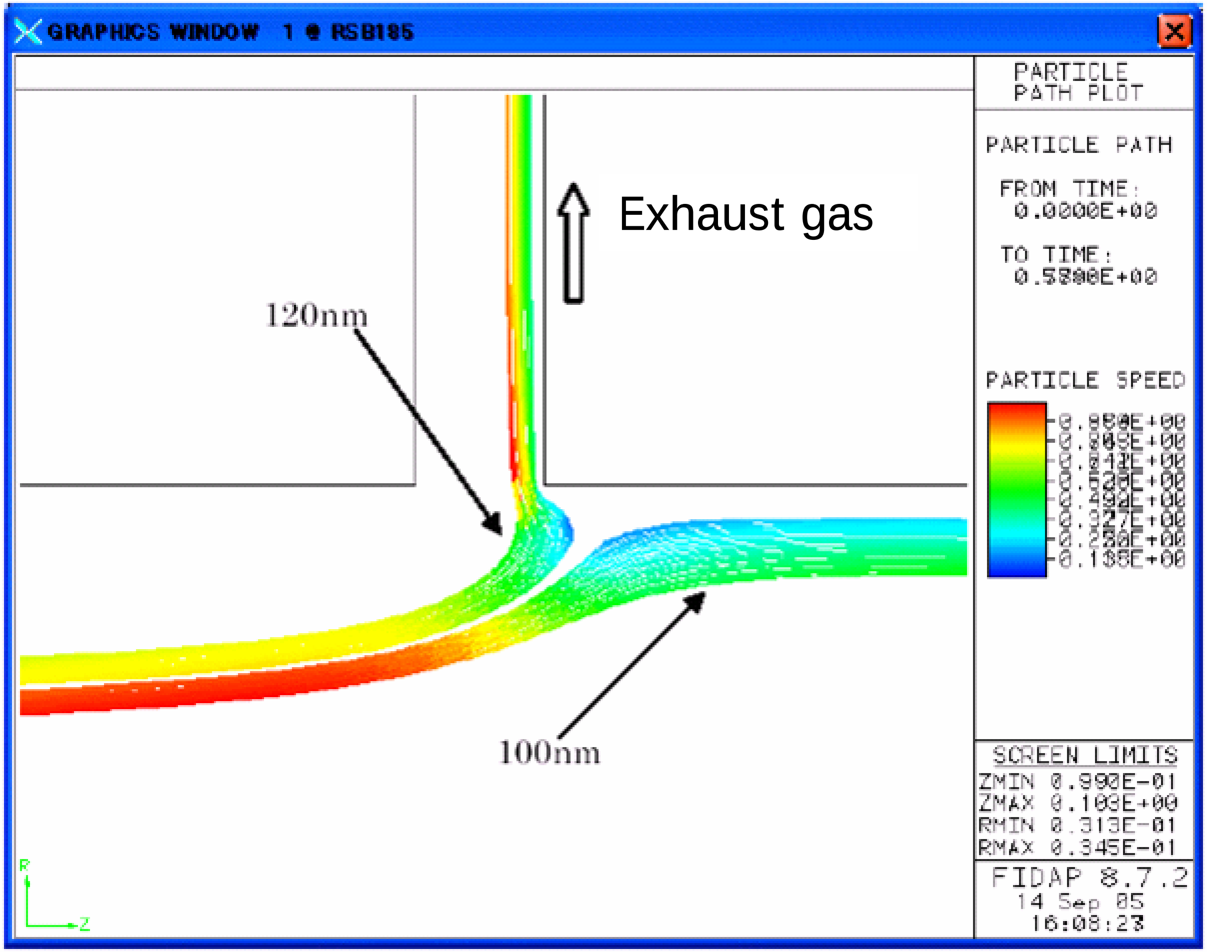

DESIGN OF THE B-DMA

Main specification of the B-DMA

Electrical source	100V(50/ 60Hz) 13A	
Ambient temperature	10～35℃	
Ambient humidity	20～95%R.H	
Ambient pressure	± 20kPaG	
Classification performance (at standard conditions)	Particle diameter	Collection rate
	17nm	0%
	30～100nm	Over 85%
	140nm	33%
Detector	Faraday cup electro-meter	
Detector noise	Under 2fA	
Foot print	50cm× 50cm	
Weight	45kg	
Measurement cycle	2Hz	

COMPARED WITH PMP SYSTEM

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- Experimental condition for static condition test

Peak engine velocity (rpm)	Load (N)
550	10
1800	366.6
2700	644.6
550	10
1800	367.2
2700	648.6

COMPARED WITH PMP SYSTEM

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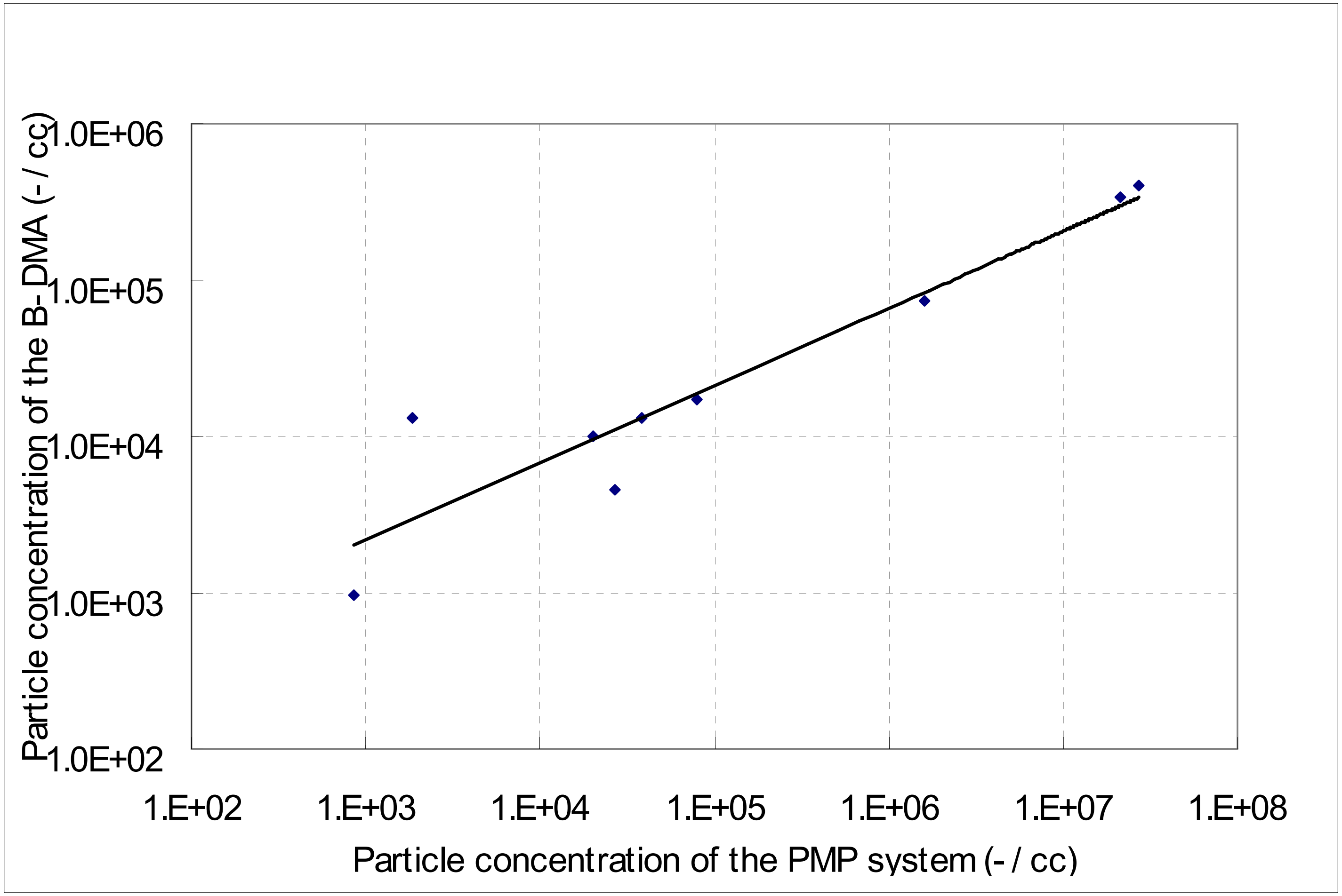
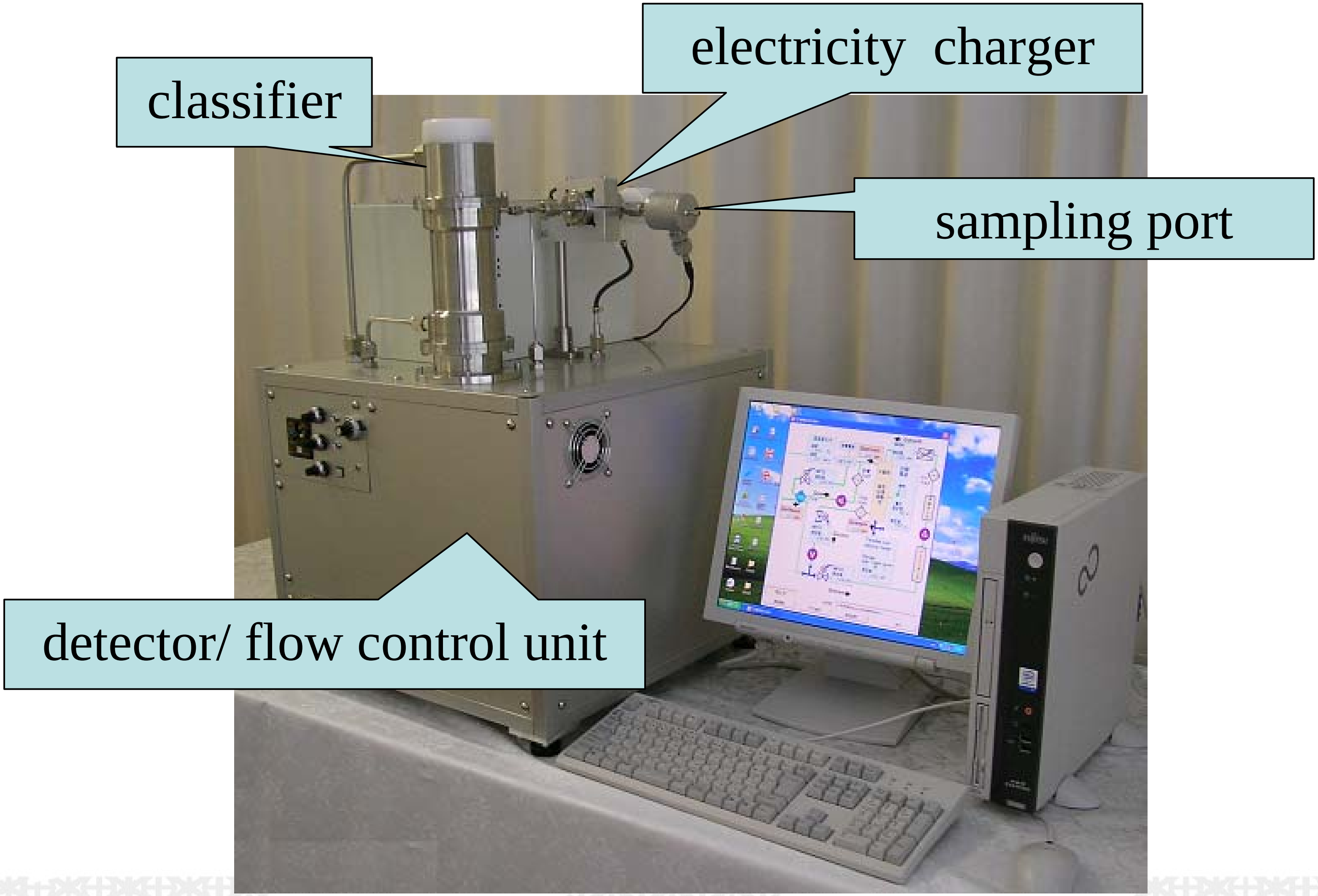


APPERANCE



classifier
electricity charger
sampling port
detector/ flow control unit

CALUCURATING CAHRGING RATIO

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