Ion Balance Measuring and Recording System for Air Ionizers

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Abstract. *Most electronic manufacturing processes require the control of Electro Static Discharge (ESD) for preventing products from damages. Air ionizers are one of the most popular devices used for controlling ESD due to their considerable cost and ease in using. However, all recent air ionizers could not measure ESD by real-time, as well as, could not automatically send measured values to the database wirelessly. Most industrial factories therefore utilize human to measure the ESD regularly as specified. This would not only lead to the lake of continuously control of ESD, but also disturb the manufacturing process and risk for high error measurement. This research presents an automatic, balanced ionizing measurement system for an air ionizer with wireless data sensing. The system consists of an analog ESD sensor, a microcontroller and a charge discharging sensor, that converts analog ESD signals into balanced ionizing values with sensor values with the decision coefficient (R2) equal to 0.944 The experimental results showed that the measured balanced ionizing values obtained from the proposed system provided low error in value between 3.067 volts - 6.957 volts in compared to the ion balance at 0 volts. The measured values could be converted into voltage in the range between -35 and +35 volts.*

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1. Introduction

Currently, the design technology for implementing the electronic devices has been continuously developing. This made them smaller than those in the past and they were able to be operated with the low-level voltage sources. Due to the size of electronic components are very small, it may be damaged from an Electro Static Discharge (ESD) [1], especially in the electronic manufacturing process which could generate ESD rapidly, and as a consequence low-quality in electronic devices [2]-[5].

Hence, the process should be required to use preventive measures to avoid ESD and electric induction [6]. In the case of cumulative charges of ESD on the insulator surface, the air ionizer is an important equipment for removing ESD in the production line. The efficiency of the ionizer was determined by 2 parameters [7] there are ion balance and decay time, Ion balance was determined by the voltage on the conductor surface, the decay time is the duration for the ionizer to resist the charge on a floating plate from the initial voltage to the desired stopping voltage. Generally, the stopping voltage has a value of ±1000 volts for the initial voltage and ±100 volts for the last voltage. To measure the efficiency of the ionizer, we can use the charged plate monitor. According to the testing standard ANSI/ESD STM3.1-2014 [8], determined the ion balance value with the static electric potential on 15x15 cm² conductor plate which called "charged plate" which is the standard requirement of Electro Static Discharge Association [9]. However, the measuring procedure of efficiency of ionizer still has problems there is measurement error, and taking a long time to measure due to the production line must be stopped while measuring.

As mentioned above, the researchers decided to improve and develop the measuring system and data transmission of the ionizer instead of the traditional method for reducing the complicated method and easy to be used.

2. Ion Balance Measurement

The Charged Plate Monitor or CPM is the measuring equipment to measure the efficiency of air ionizer according to the testing standard ANSI/ESD STM3.1-2015 [10] and IEC 61340-4-7 [11] there is the standard testing method (STM) to estimate the ionizer. STM determined ion balance when static electric potential appears on a 15x15 cm² conductor plate with a capacitance of 20 pF which is called CPM. The ionizer provides a positive charge and a negative charge at the same time [12]. The released charge is attracted to the surface which has an opposite charge and neutralized. The motion of both ions depends on the velocity of air which could be explained by equations (1)-(2) [13]-[15]

$$\frac{\partial n_n}{\partial t} + \nabla \cdot (n_n u_n) - D_n \nabla^2 n_n = -\beta n_p n_n \quad (1)$$

$$\frac{\partial n_n}{\partial t} + \nabla \cdot (n_n u_n) - D_n \nabla^2 n_n = -\beta n_p n_n \quad (2)$$

After that, we can explain ion balance by static electric potential V depend on the density of a positive ion and a negative ion

$$\nabla^2 V = \frac{-e\left(n_p - n_n\right)}{\varepsilon_0} \tag{3}$$

The charge ρ_v quantity depends on the primary charge and the balance of a positive ion density (n_p) and a negative ion density (n_n)

$$\nabla^2 V = -\frac{\rho_v}{\varepsilon_0} \tag{4}$$

The electric potential of equation (4) to find the electric field

$$E = -\nabla V \tag{5}$$

The charged plate (S) is perpendicular to the magnetic field (E) and can store the charge (Q) with directly proportional

$$Q = \varepsilon_0 \varepsilon_r E_S S \tag{6}$$

The electric potential on a charged plate is directly proportional to the charge quantity but inversely proportional to the capacitance [16]

$$V = \frac{Q}{C} \tag{7}$$

3. Research Methodology

The structure of ion balance measuring of the ionizer as Fig. 3 and 4 consists of 2 parts there are hardware part and software part as follow;

3.1 The structure of a sensor for measuring the ion balance

The system to measure the ion balance of the ionizer shown in Fig.1-2 consists of the following parts:

1. The sensor to measure the ion balance [16].

2. The IC chip to transfer an analog signal to a digital signal (MCP3208).

3. Raspberry Pi 3 Model B.

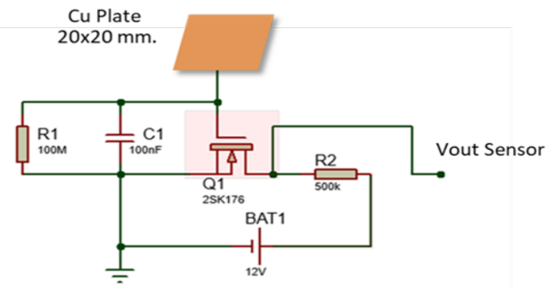

Fig. 1: Diagram of an ESD sensor

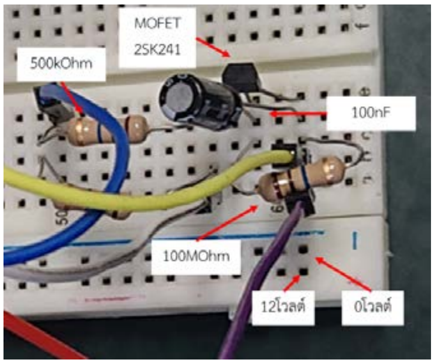

Fig. 2: an ESD sensor

From the ESD sensor circuit (Fig.2), the voltage dropped between the source pin and gate pin of a MOSFET (V_{GS}) is the voltage generated from the electric field of the ionizer when the voltage was biased, it would make a flowing current which is I_D as equation (8) [17]-[18]

$$I_D = K_n \left(V_{GS} - V_{TH}\right)^2 \tag{8}$$

When K_n is a transconductance parameter

V_{TH} is a threshold voltage

V_{GS} is a voltage drop between Gate pin and Source pin

V_{DS} is a voltage drop between Drain pin and Source pin

and can find the voltage V_{DS} from equation (9) which is the output voltage of a sensor

$$V_{DS} = V_{DD} - I_D R_D \tag{9}$$

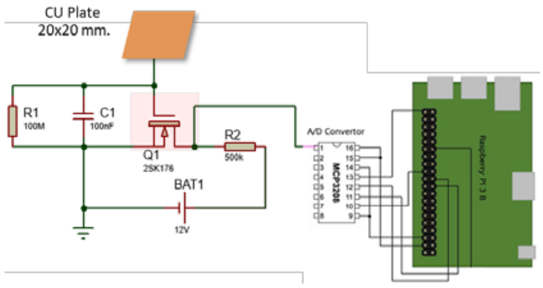

Fig. 3: The wiring of an ESD sensor to Raspberry Pi board

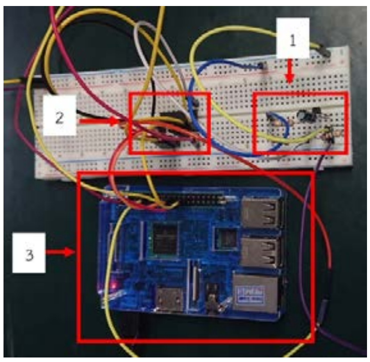

Fig. 4: The circuit of an ESD sensor

The standard charge plate was 20 pF and had a large size when installed permanently to the case. therefore, the researcher chose the charged plate (copper plate) with a size of 20x20 mm^2 and thickness of 1 mm [8] instead of the standard charged plate in order to fit well with the blower, shown in Fig. 5 while the installation is shown in Fig.6.

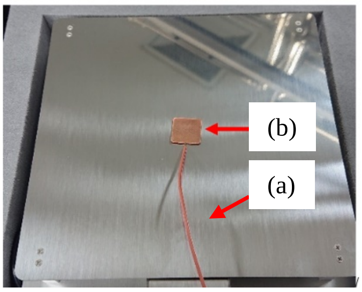

Fig. 5: (a) a standard charged plate when compared with (b) a copper plate

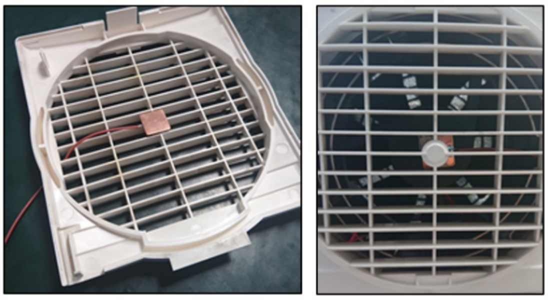

Fig. 6: a charged plate which installed on the front side of the ionizer

4. Experimental Results

From Fig.7 and Fig. 8, there is the measuring of the ion balance and decay time. the CPM plate placed away from the ionizer around 45 cm. and 15 cm. from the ground and then measure the RMS voltage of an ESD sensor to find the correlation of both factors.

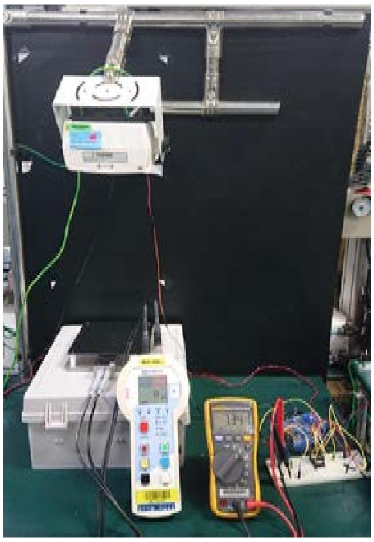

Fig. 7: The photograph of the experimental test-rig

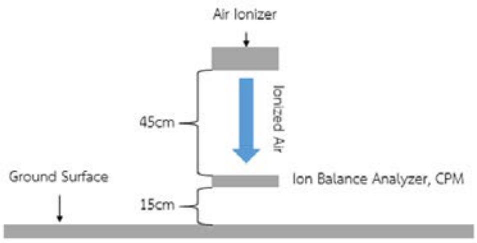

Fig. 8: The position of installation

4.1 The experimental tests to determine the transfer equation from electric voltage to ion balancing scale

The experimental tests to determine the transfer equation from electric voltage to ion balancing scale was to find the correlation between the voltage from an ESD sensor and the ion balance from SIMCO which were measured and recorded at the same time. The test results are shown in Fig. 10, then find the mean value in each time and then created the chart of distribution.

Fig. 9: The measuring of the output voltage of a sensor and the ion balance of the CPM

The measuring and storing in this experimentation would be adjusted the value of the ion of the ionizer from -80 V to +80 V continuously, then read the value from the ion balance measuring equipment (SIMCO EA-5J) and ESD sensor and then analyze the data to find the regression line between the ion balance of CPM and the proposed sensor using Minitab.

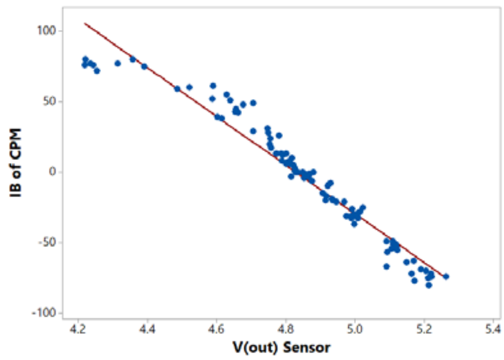

Fig. 10: The correlation between output voltage from the sensor and CPM

When taking the ion balance (vertical axis) and the voltage (horizontal axis) to create a graph which provides the correlation equation between the ion balance of CMP and the proposed sensor as equation (10)

$$y = -172.23x + 831.91 \quad (10)$$

When y is the ion balance of CMP

x is the ion balance of sensor

and Coefficient of determination (R^2)

$$R^2 = 0.9435 \quad (11)$$

4.2 Comparison of the result of ESD measuring between the ion balance of CPM and sensor

From equation (10) is the correlation between the output voltage from the sensor and the ion balance of CPM number 1. After the correlation equation is obtained, then transfer the output voltage to the ion balance with the correlation equation and then compare it with other CPM.

4.2.1 Comparison of the result of ESD measuring between the ion balance of CPM and sensor from microprocessor number 1

Fig.11 is the measuring of ion balance of CPM from -80 V to +80 V and takes the correlation of both values with the coefficient of determination of 0.989, the relative error of 5.2 volts, and the standard deviation of 3.803

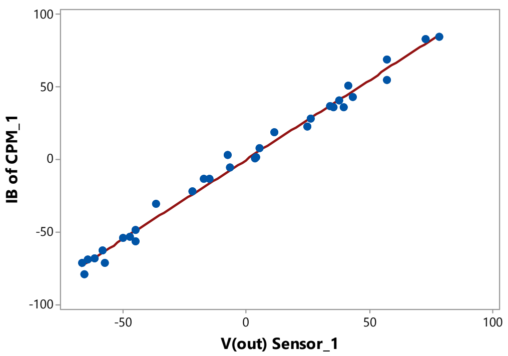

Fig. 11: Comparison of the result of ESD measuring between the ion balance of CPM and sensor from microprocessor number 1

Table 1 is the measuring of the ion balance of the sensor and CPM from microprocessor number 1 at the ion balance is 0 volt and repeats the measurement for 31 times which gets a relative error of 3.067 V, and the standard deviation of 2.174.

IB CPM (Volts)	V_{out} Sensor (Volts)	IB Sensor (Volts)	Error
1	4.820	1.761	-0.761
-2	4.832	-0.305	-1.695
-3	4.819	1.934	-4.934
-1	4.839	-1.511	0.511
-3	4.849	-3.233	0.233
-3	4.866	-6.161	3.161
-3	4.824	1.072	-4.072
2	4.850	-3.405	5.405
-3	4.864	-5.817	2.817
-4	4.873	-7.367	3.367
2	4.815	2.623	-0.623
-1	4.840	-1.683	0.683
1	4.852	-3.750	4.750
-5	4.825	0.900	-5.900
0	4.855	-4.267	4.267
0	4.839	-1.511	1.511
2	4.829	0.211	1.789
-4	4.855	-4.267	0.267
1	4.847	-2.889	3.889
-5	4.835	-0.822	-4.178
-3	4.861	-5.300	2.300
-5	4.871	-7.022	2.022
-4	4.815	2.623	-6.623
-2	4.863	-5.644	3.644
-2	4.841	-1.855	-0.145
-3	4.840	-1.683	-1.317
2	4.843	-2.200	4.200
-5	4.827	0.556	-5.556
2	4.873	-7.367	9.367
-5	4.867	-6.333	1.333
-1	4.858	-4.783	3.783
Average			3.067
SD.			2.174

Table 1 The measuring result of the ESD of the sensor and CPM from microprocessor number 1 at the ion balance is 0 volt

4.2.2 Comparison of the result of ESD measuring between the ion balance of CPM and sensor from microprocessor number 2

Fig.12 is the measuring of ion balance of CPM from -80 V to +80 V and takes the correlation of both values with the coefficient of determination of 0.972, the relative error of 6.2 volts, and the standard deviation of 5.002, while Table 2 shows the corresponding results of the above test.

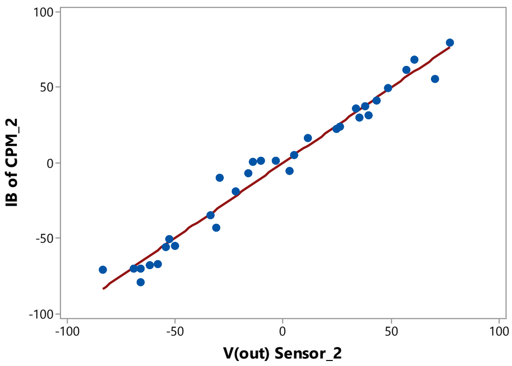

Fig. 12: Comparison of the result of ESD measuring between the ion balance of CPM and sensor from microprocessor number 2

IB CPM (Volts)	V_{out} Sensor (Volts)	IB Sensor (Volts)	Error
1	4.814	2.795	-1.795
-2	4.872	-7.195	5.195
3	4.832	-0.305	3.305
-1	4.889	-10.122	9.122
3	4.786	7.617	-4.617
1	4.861	-5.300	6.300
-2	4.789	7.101	-9.101
3	4.888	-9.950	12.950
1	4.855	-4.267	5.267
-2	4.857	-4.611	2.611
-2	4.895	-11.156	9.156
3	4.787	7.445	-4.445
4	4.890	-10.295	14.295
-2	4.861	-5.300	3.300
3	4.838	-1.339	4.339
6	4.851	-3.578	9.578
0	4.809	3.656	-3.656
3	4.856	-4.439	7.439
2	4.801	5.034	-3.034
4	4.830	0.039	3.961
4	4.831	-0.133	4.133
5	4.871	-7.022	12.022
2	4.880	-8.572	10.572
2	4.881	-8.745	10.745
5	4.803	4.689	0.311
4	4.886	-9.606	13.606
6	4.872	-7.195	13.195
4	4.859	-4.956	8.956
-3	4.801	5.034	-8.034
0	4.846	-2.717	2.717
1	4.855	-4.267	5.267
Average			6.872
SD.			3.842

Table 2 The measuring result of the ESD of the sensor and CPM from microprocessor number 2 at the ion balance is 0 volt

From Table 2, It shows the measuring of the ion balance of the sensor and CPM from microprocessor number 2 at the ion balance is 0 volt and repeats the measurement for 31 times which gets a relative error of 6.872 V, and the standard deviation of 3.842.

4.2.3 Comparison of the result of ESD measuring between the ion balance of CPM and sensor from microprocessor number 3

Fig.13 is the measuring of ion balance of CPM from -80 V to +80 V and takes the correlation of both values with the coefficient of determination of 0.978, the relative error of 5.837 volts, and the standard deviation of 4.797.

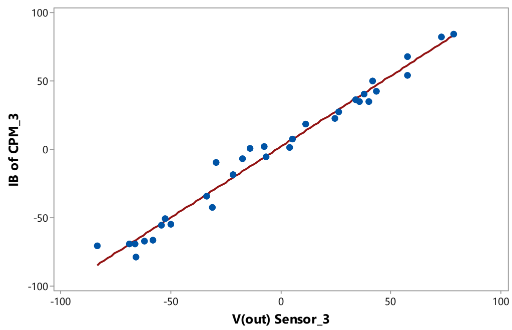

Fig. 13: Comparison of the result of ESD measuring between the ion balance of CPM and sensor from microprocessor number 3

Table 3 is the measuring of the ion balance of the sensor and CPM from microprocessor number 3 at the ion balance is 0 volt and repeats the measurement for 31 times which gets a relative error of 6.957 V, and the standard deviation of 5.128.

IB CPM (Volts)	V_{out} Sensor (Volts)	IB Sensor (Volts)	Error
0	4.909	-13.567	13.567
-2	4.920	-15.462	13.462
0	4.861	-5.300	5.300
2	4.886	-9.606	11.606
-3	4.825	0.900	-3.900
2	4.882	-8.917	10.917
0	4.848	-3.061	3.061
-2	4.859	-4.956	2.956
2	4.886	-9.606	11.606
-1	4.869	-6.678	5.678
2	4.836	-0.994	2.994
1	4.927	-16.667	17.667
3	4.854	-4.094	7.094
2	4.862	-5.472	7.472
-3	4.891	-10.467	7.467
0	4.829	0.211	-0.211

0	4.842	-2.028	2.028
-1	4.870	-6.850	5.850
3	4.867	-6.333	9.333
-3	4.885	-9.434	6.434
-3	4.891	-10.467	7.467
3	4.879	-8.400	11.400
1	4.900	-12.017	13.017
-2	4.873	-7.367	5.367
-2	4.869	-6.678	4.678
-1	4.870	-6.850	5.850
2	4.870	-6.850	8.850
0	4.824	1.072	-1.072
2	4.860	-5.128	7.128
-1	4.902	-12.361	11.361
-3	4.824	1.072	-4.072
Average			6.957
SD.			5.128

Table 3 The measuring result of the ESD of the sensor and CPM from microprocessor number 3 at the ion balance is 0 volt

4.3 Storing the data of the ion balance to the database

For storing the data of the ion balance to the database would store it in the database named smart_esd and the data table named air_ionizers. In the table has 5 columns consists of the name of the production line, station name, the number of the machine, date time, and the ion balance from equation (10)

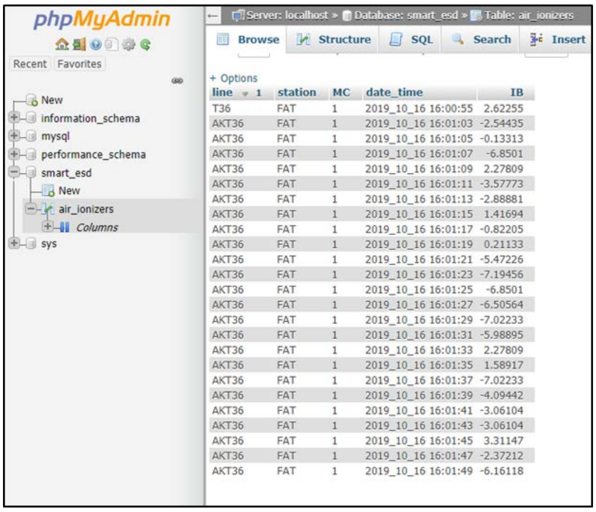

Fig. 14: The storage data in the created database

5. Conclusions

This paper proposed a new design and creation of the measuring and storing system of the air ionizer. The experimentation in topic 4.1 is the procedure to find the correlation between ion balance which is measured from Charged Plate Monitor or CPM and the output voltage of the sensor by the coefficient of determination of 0.9435 and correlation equation (4.1), then compare the correlation equation from the sensor with the ion balance from the ionizer at the ion balance is 0 volt of a machine number 1 with a relative error of 3.067 volts, a machine number 2 with a relative error of 6.872 volts, and a machine number 3 with a relative error of 6.957 volts which could refer the ion balance of CPM in the range from -35 V to +35 V which is following the standards of the company.

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