

## Research Article

### Design and Implementation of Electrostatic Spraying Automatic Controlling System Based on PLC

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**Abstract:** The objective of this study was to improve the spraying efficiency and meet the demand of modern agricultural. A new generation of electrostatic sprayer which we designed realized the goals. The automatic controlling system is successfully designed. PLC (Programmable Logic Controller) was taken as the control core of the system and LCD touch screen was employed for human-computer interaction interface. The system integrates kinds of techniques including programming, pressure monitoring and sensor technology, etc. The main structure of this equipment, working principle and control system hardware selection will be also introduced in the study. Human-computer interaction software was programmed by the software of Pro Tool/Pro CS. System controlling software was programmed in form of ladder diagram, which realized kinds of functions including ESD protection, accurate quantification, automatic controlling and humanized operation. Test results show that the effective spraying range is between 5 to 6 m, the Volume Median Diameter (VMD) is 47.48  $\mu\text{m}$  and the Ultra-Low Volume spray (ULV) is realized. The spray deposition rate and effective availability of pesticide is higher than old sprayer. And also this new sprayer runs steadily.

**Keywords:** Automatic control, electrostatic spray, PLC, pressure pulsation

## INTRODUCTION

In order to reducing the harm to the environment and people, the research and development of plant protecting machine focus on improving the mechanical work efficiency and the effective availability of pesticides. This opinion has agreed among people all over the world, especially in the developed countries. They try to working out special equipments for spraying pesticide according to different plants and try their best to improve mechanical automation (Yu, 2008). Electrostatic spraying technology was developed since 1960s. Electrostatics is an ancient science, with well established basic laws (Molini, 2009). After the droplets is charged, which will fly to the target under the flow field force and electric field force, it not only enhances the adhesion lability of the droplets, but also eliminate the loss of pesticide from drift onto unintended target and the pollution of the environment, (Can *et al.*, 2007). Chadd (1990) have done some laboratory tests of the de-insectization effects of a small, electric sprayer and the results show that using deflection electrode can enhance synthesis chrysanthemum fat precipitation amount. I W Kirk have used high pressure electrostatic spraying technology in the air spraying. He tested in the cotton fields, which

proved that electrostatic spray compared to the Traditional Pesticide Application (TPA), pesticide deposition in plant surface increased and the drifting losses reduced (Kir *et al.*, 2001). Thomas *et al.* (2000) has researched the surface of the plant which is sprayed by the high pressure electrostatic spraying. He has used multiple nozzle in the test. He indicated that when the nozzle spacing is 50cm and high pressure is 45 KV, plant surface precipitation amounted far greater than without the operation condition of the electricity. In China, Jiangsu University was the representative of this research. They developed electrostatic sprayer in 1999. Jia *et al.* (2008, 2011b) and some other people made high deposition experiment of the device and the tests showed that it can get no less than 50% of the deposition rate in the reasonable distance. In this study, we improved the original sprayer and a new generation of electrostatic sprayer which based on PLC automatic control is successfully designed, this sprayer can work for the greenhouse, shed and so on.

## MAIN STRUCTURES AND WORKING PRINCIPLES

New spraying machine consists of three parts, spray directional rotation control system, liquid supply

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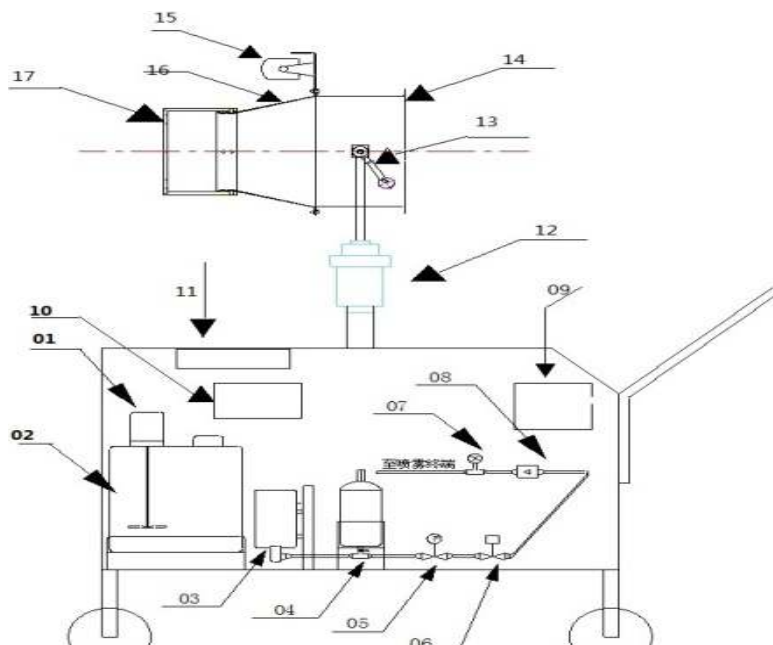


Fig. 1: The structure schematic of electrostatic sprayer system

- 1: Agitator; 2: Spray tank; 3: High-pressure diaphragm pump; 4: Pressure pulsation damper; 5: Pressure regulator; 6: Solenoid valve; 7: Flow sensor; 8: Pressure sensor; 9: PLC control cabinet; 10: UPS; 11: High-Voltage Power Supply (HVPS); 12: Slewing mechanism; 13: The elevation adjusting handle; 14: Blower; 15: Hd camera; 16: Hair dryer; 17: Electric unit

Table 1: Performance parameters

Kinds of device		Parameters
Eninge (KW)		0.32
Capacity of spray tank (L)		25
High-voltage power (kV)		0~25 (adjustable)
Holder of rotation angle		0~180° (adjustable)
Spray angle		-30°~+45°
Speed of agitator (rpm)		0~60 (adjustable)
Detection of residual pesticide		6 files (0~100%)
Detection of remaining power		6 files (0~100%)
Blower	Wind volume (m3/h)	2700
	Wind pressure (Pa)	260
	Revolving speed (rpm)	2300
Sprayer	Discharge rate (ml/min)	80±10%
	Spray pressure (MPa)	0.2~0.4
	VMD (μm)	30~80
Pressure pulsation damper	Adjustment range of pressure pulsation (MPa)	0~1
	Controlling kinds	Manual operation/program control

system, pressure pulsation of self adjusting system, high voltage electrostatic generator with power supply system, electric control system, which is shown in Fig. 1.

**Spray directional rotation and monitoring devices:** It is mainly composed of a blower fan, elevation rotating handle, a rotating bracket, rotating mechanism, wind tube with variable diameter, high-definition camera

components. They are mainly used to control spray azimuth and angle, send the tiny droplets to the target area and observe the spray state. The main performance parameters are shown in Table 1.

**Pesticide supply system:** This system includes spray tank, agitator, high-pressure diaphragm pump, solenoid valve, pressure regulator, etc. It is used to store pesticide and conduct on-line liquid mixing. Pesticide is fully mixed with water and sent to nozzle through the control of solenoid valve and pressure regulator.

**Pressure pulsation damper system:** This system includes pressure sensor, PLC, Magneto-Rheological Fluid Damper (MRFD) etc. They are shown in Fig. 2. Self adjusting system of Pressure pulsating in pipeline make the liquid pressure maintain as a constant value, so the pressure pulsation can be automatically adjusted.

**High voltage electrostatic generator and power supply system:** It is mainly composed of a charging wire disc, UPS power system, High Voltage Power Supply (HVPS), charging unit (include 16 electrodes) (Doe *et al.*, 2012). It supplies energy for the whole system. High voltage electrostatic generator can generate high voltage and charges droplets on the electrode.

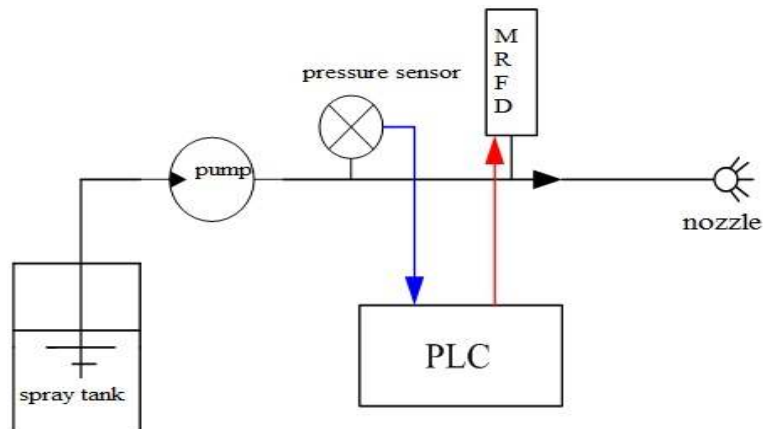


Fig. 2: The control system of pressure pulsation damper based on Magneto-rheological fluid damper

**Electric control system:** PLC (Programmable Logic Controller) is taken as the control core of the system and LCD touch screen is employed for human-computer interaction interface. It is an integrated automation control system which combines techniques including programming, pressure monitoring and sensors, etc. Finally, it is a success to automatically control the electrostatic spraying.

**Working principle of control system:** Electrostatic spray car has two control modes, manual or program control. When choosing the manual control mode, the UPS button of the car switches on and the control of total power is turned on, regulating switch, implementing the start of ventilation system, hybrid system, electromagnetic valve and the spray system. When choosing the program control, switching regulator will change to program control button, the touch screen is provided with the manual and procedure control buttons.

When program control, first start the blower controlled by the PLC. Waiting for 5 sec after the stability work of the fan and start high voltage electrostatic module, then start the agitator and activate the pump to spray. Waiting for 2 sec, electromagnetic valve will work. Pressing the "pan head" button can adjust the spray direction. When the spray direction meets the requirement, stop the button. Using angle adjusting handle on both sides of the wind tube can adjust elevation angle of the spray.

#### AUTOMATIC CONTROL SYSTEM

The automatic control system is mainly composed of the hardware and software. Principle of the control system is illustrated in Fig. 3

**Hardware selection:** The PLC system employs SIEMENS S7-200 series, it includes 22 input points, 12 output points and the type of CPU is 224 CN (14DI/10DO). The expansion module of analog output is EM231 (3DO) (Wei, 2011). The type of the LCD touch screen is SIEMENS TP120B. The communication between PLC and Touch screen is RS485 port. The type of the pressure sensor is HM20; also we use the Vanton turbine flow sensor.

**Software design:** The controlling software is comprised with Human-computer interaction software and the control system software.

**Human-computer interaction software:** The SIMATIC ProTool/Pro CS is used to write the software and the program is stored in the touch screen memory. It is mainly used to input and output the spray machine's parameters (Matched power, Container capacity, revolving speed, rated power) and work information (air volume, spray volume, electrostatic voltage, pressure pulsation state). The corresponding reference data also can be read. The software includes 6 interfaces. They are start interface, the manual control of main menu (Fig. 4), program control menu and the regulation menu of electrostatic voltage. All interfaces have numerical input dialog box, information output dialog box and some buttons to transport the order or the data to PLC. In the mean time, we also can get information from PLC. Human-computer interaction is successfully designed (Hu and Hu, 2007).

**System monitoring software:** The software is the core of control (Program diagram as Fig. 5). The program is showed in personal computer in form of ladder diagram under Step7-Wicro/WIN programming environment.

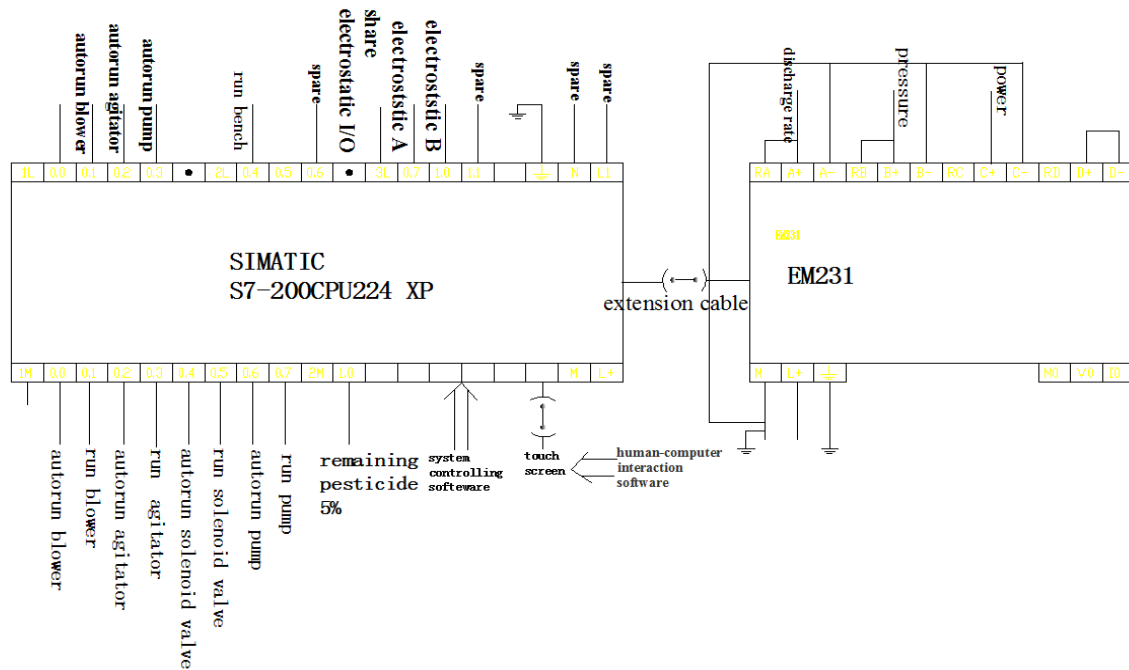


Fig. 3: The principle diagram of the automatic control system

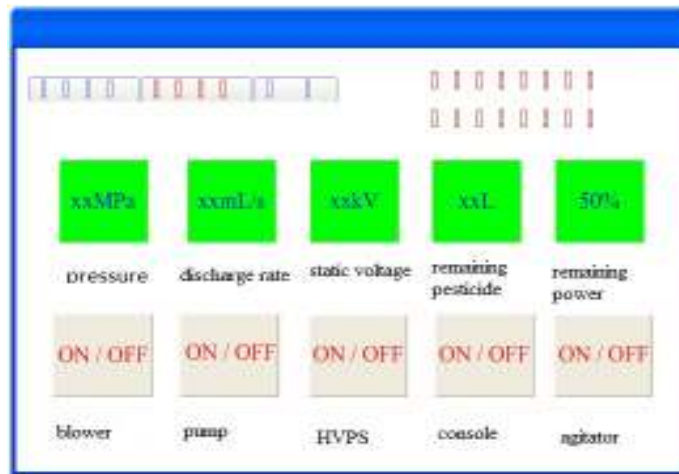


Fig. 4: The controlling menu of main touch screen

After editing and commissioning, programs are downloaded to PLC. The mainly functions are as follows:

- First, every part of the equipment will cooperate well and work orderly according to different conditions.
- Second, we set some programs in the software. In this way, information could be input by the touch screen, such as delay of the pesticide mixture (mixture time of water and pesticide), delay of

static (the time from the start of fan to the static being generated), pump delay (the time from the pump being opened to the stable spraying), etc. During the whole experiment, it always needs to keep the electrostatic and insulation and keep the pressure stable, so that the pesticides are fully mixed and the work quality and safety of spray are improving.

- Third, software for fault (such as no liquid, no power, no voltage fault etc.) will raise alarm or terminate the whole work, ensuring the security of

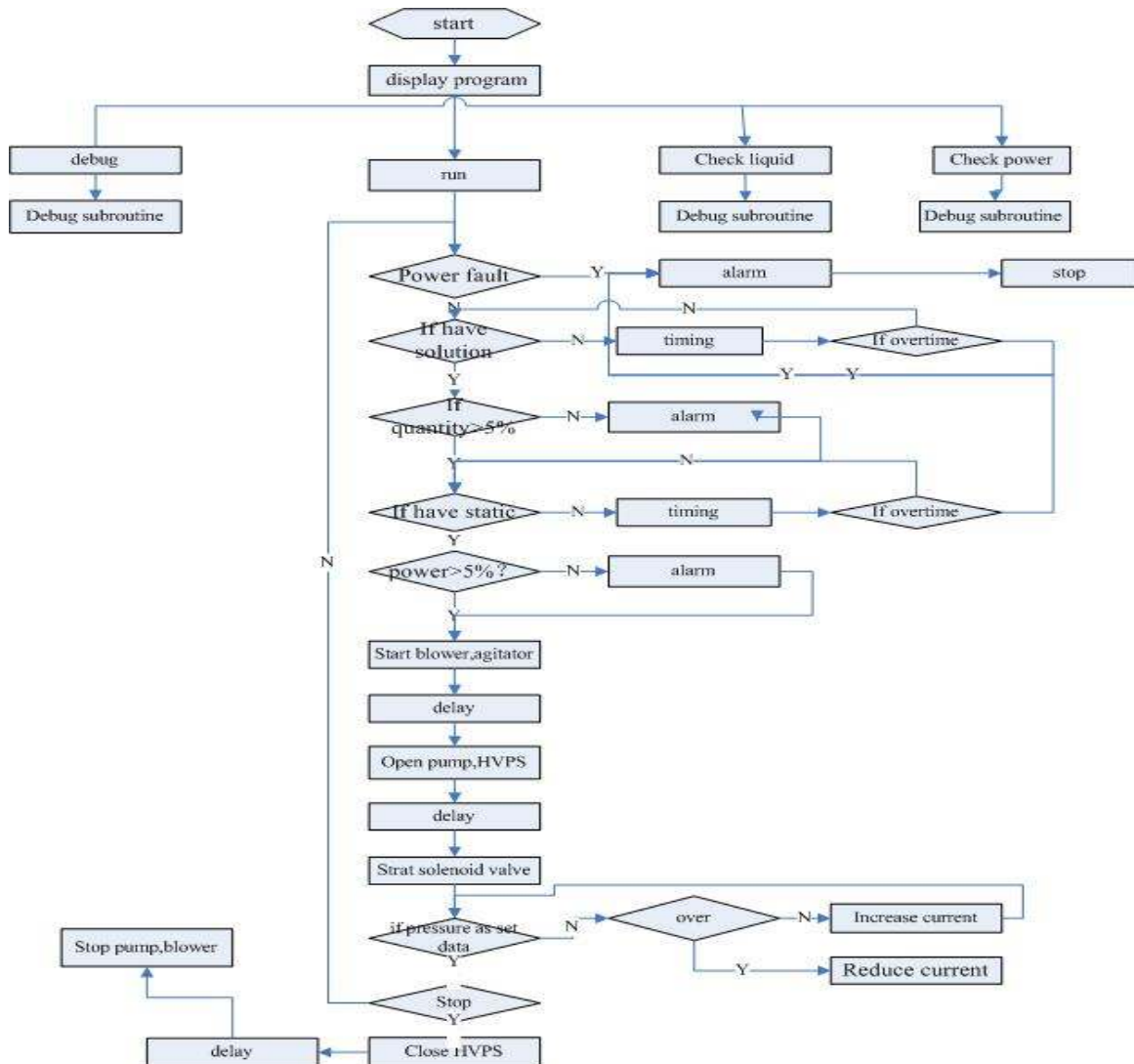


Fig. 5: The software program diagram of monitoring system

the person and equipment as well as operating well. The flow sensor, pressure sensor and other sensors of different functions have different software module.

- Fourth, the software monitors the spraying pressure, flow, electrostatic voltage, residual quantity and the remaining power, which are displayed in digital signal in the corresponding position of the touch screen on time. "The pressure pulsation state" indicates the real-time monitoring system's pressure change and represented by the curve. When the liquid is insufficient, it will warn that "add the pesticide, please"; when the power supply is insufficient, it will issue a warning "electricity shortage, please recharge".

- Fifth, the most important role of the software is to solve unstable pressure control. PLC conducts real-time detection of the liquid pressure in the pipeline by pressure sensor. When the liquid pressure exceeds a critical value, PLC decreases MRF damper coil current to absorb excessive pressure in pipeline; when the fluid pressure falls below a critical value, PLC increases MRF dampers coil current to increase liquid pressure in the pipeline. So the liquid pressure in pipeline remains constant and the pressure pulsation can be automatically adjusted. The state of pressure pulsation will be shown in Fig. 6.

**Anti-interference measures:** This electrostatic sprayer is mostly used in greenhouse, field, shed. Because of

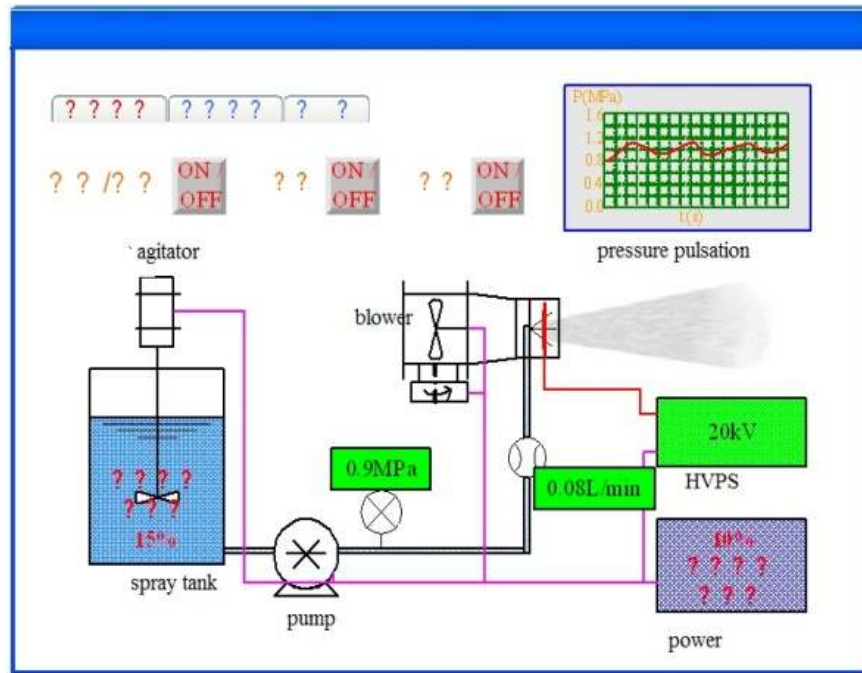


Fig. 6: The state of pressure pulsation

high humidity and the adverse circumstances, in addition, using high voltage electrostatic generator could be a serious interference source. If measures are not taken, not only PLC program will be out of control, but also solenoid valve and normal work will be influenced. Therefore, anti-interference measures have been taken in both hardware and software:

- First, we design an independent switching power supply for PLC and the PE points contact well with the ground.
- Second, in order to eliminate the power supply impulse voltage and electrical spark influence weak current, main contact of the contactor connect with the voltage dependent resistor (Li, 2005).
- Third, high and low voltage wires are separated, the spacing is over 15cm. All the wires are designed to insulate against the equipment shell.
- Fourth, the high voltage electrostatic generator was encapsulated by resin and rubber. Also we make the outside shield reliably grounded. Because of preventing election from hurting people, high-voltage power should open after the system was working steadily.
- Fifth, after reading the datum from every sensor, we confirm the datum which could lasts for few seconds. There's no doubt that datum misread which caused by occasionally interference will

eliminate. That's why in this program, we designed 'no-pesticide delay', 'off-delay operation' and 'over-voltage protection'.

### PERFORMANCE TEST AND ANALYSIS

To evaluate the whole performance of the spray device, during the development process, the spray process in the specific conditions has been measured, including airflow velocity and the particle size.

**Airflow velocity:** To evaluate gas phase attenuation performance of the device, we use the hot wire anemometer to measure the wind velocity at different positions. The results show that at 0 m outlet velocity is up to 12.5 m/s, at 5 m outlet velocity decreases to 1.2 m/s and at 6 m the wind velocity is nearly zero. Therefore, it can be identified that the farthest distance of the droplets which is led by air can reach about 5 to 6 m away from the sprayer. The higher the axial velocity, the stronger the perturbation influence on crop branches and leaves by axial flow and the velocity of the droplets will be higher, the penetrability will be stronger. Axial flow can improve the greenhouse spraying equipment's spraying width effectively, the distribution of the axial velocity is a quadratic curve, the smaller the distance away from sprayer, the higher the axial velocity will be and the decay will be more obvious. On the contrary, when closing to sprayer, it is obviously that the



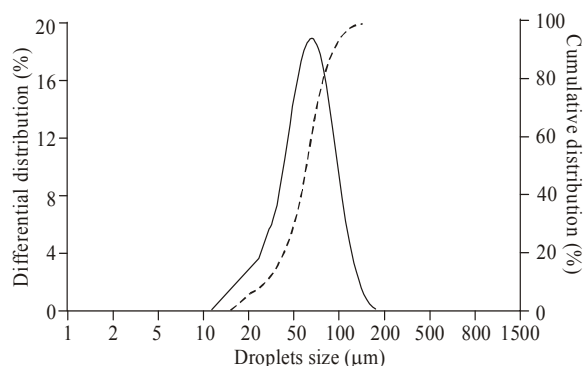


Fig. 7: Distribution of droplets size in the one meter position

influence of axial flow to improve deposition rates of the droplets (Jia and Li, 2011a).

**Droplets size distribution:** In order to compare the droplet diameter size and its distribution affected by the existence of electrostatic, the fan is closed to preclude axial airflow effects; the Phase Doppler Particle Analyzer (PDPA) is used to measure the droplet size. The feature parameters and distribution of droplets size in the one meter position of D50 are shown in Fig. 7. The value of D10, D50 and D90 usually are used in cumulative integral to evaluate general situation of droplets size distributions. The more difference among the three values is the more non-uniformity the droplets size distribution will be. In addition, because D 50 is close to the average particle size, we often use this value to evaluate the particle size. According to the measurement, the value of D 50 is 47.48  $\mu\text{m}$ , which shows that the droplet size is 47.48  $\mu\text{m}$ . Good atomization effect can produce many small droplets, which have a small gravity and the resistance in the airflow from fan. That's why they can be sent to a further afield by high-speed airflow, it means spray span is larger (Zhang *et al.*, 2006). In the determinate spray conditions, larger kinetic energy will lead to the droplet impact in plant target interface that makes it easy to rebound or splash. Therefore with the larger droplets size and the increasing of the average speed, the uncharged droplets hardly adheres to target plant area. Compared with the uncharged, small charged droplets group can raise the ability of drift because of the larger kinetic energy.

**ULV spray:** Through test the discharge rate of the sprayer, the range of the rate is  $80\pm 10\%$  (mL/min), which is Ultra Low Volume spray (ULV). The advantages are high efficiency, less pesticide high concentration and the long-time efficacy. The proportion of medicament which adheres on crops is

better. According to references, ultra low volume sprayer can produce droplets as much as 100 times more than knapsack manual sprayer when using the same volume of water. According to tests, coverage density of droplets is 1000 droplets per square centimeter when the ultra low volume sprayer works normally. However, it is only 10 droplets per square centimeter when the knapsack manual sprayer is working. 1000 droplets square centimeter means 100% area are covered. No matter how smaller insects or germs are, they will touch the pesticide. If coverage density of droplets is ten droplets per square centimeter, most of insects can't be killed. Therefore, ultra low volume sprayer uses less water, but the effect is improved (Ma, 2004).

**Tests of other performances:** The performances and stability have been tested in the national plant protection machinery quality supervision and Inspection Center in China. They test the pressure resistant performance of the spraying pipe and the sprayer works five minutes. The results show that the pipe don't leak anymore when sprayer is working. The system runs twice continuous in the condition of rated pressure and speed. It work 15 min once, there are no abnormal vibration. The quality of the assembly is tested, the results show that the active parts rotated flexibly. Every part fastened strongly and reliable. There are no askew and warping parts.

## CONCLUSION

- First, PLC is taken as the control core of the system. LCD touch screen is employed for human-computer interaction interface. The sprayer realizes kinds of functions including ESD protection, accurate quantification, automatic controlling and humanized operation. Every part cooperates well. It is convenient for data input and read.
- Second, lots of anti-interference measures have been used in the hardware and software. This sprayer also can work stably and reliably in the electromagnetic interference environment. Tests proves that the sprayer works with no abnormal vibration and do not drip. The effective distance is 5~6 m, wind speeds up to 12.5 m/s in the export. It increases the spray span effectively.
- Third, the Volume Median Diameter (VMD) is 47.48 $\mu\text{m}$ . The Ultra Low Volume spray (ULV) could avoid the low deposition rate. The advantages are high efficiency, less pesticide and the long-time efficacy. Therefore, it increases the utilization rate of the pesticides.

Finally, this machine combines of the automatic control and manual control integrated. It can use in various environment. For the traditional sprayer, electrical gas control is rough and simple, structure design is not reasonable and the effective utilization rate of pesticides is low. This new design has fundamentally changed the situation.

#### ACKNOWLEDGMENT

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