Design of Farm Machinery

Prof. Hifjur Raheman
Agricultural and Food Engineering Department
Indian Institute of Technology Kharagpur
Week – 10

Lecture 47 : Solar Energy operated unmanned sprayer

Hi everyone, this is Professor H. Raheman. I welcome you all to this SWAYAM NPTEL course on Design of Farm Machinery. This is lecture 47, where I will try to cover the design of a solar energy-operated unmanned sprayer. The concepts which will be covered: design of a self-propelled sprayer, then we will try to utilize those design parameters and develop a solar energy-operated unmanned sprayer.

The components of a self-propelled sprayer: spraying unit, storage unit, propelling unit, and power supply unit. To make it unmanned, you require an additional component called a transceiver unit. So, let us now see what the spraying unit is, how you are going to design it? and what factors we will consider? The spraying unit includes the selection of a nozzle, boom, boom width (boom means boom width), operating pressure, and the pump. So, knowing the crop for which spraying is to be carried out, the type of nozzle, percentage of overlap, number of nozzles, and spraying height are to be decided. So, for the application of liquid pesticides to the crop, we go for hollow cone nozzles or flat fan-type nozzles, and there you have to take a minimum 60 per cent overlap.

So, row-to-row spacing is taken from the agronomical requirement. For example, if it is groundnut, then 50 centimeters; maize, also 1 meter. So, these are some of the data which have to be taken from agronomical requirements. Then, once you decide the crop, taking the agronomical factors, we assume that each row is provided with a single nozzle. And then, depending on the spacing, we have to decide how many, depending on this overlap, we have to decide what will be the spacing between two adjacent nozzles. Then, once you decide the number of nozzles, we have to decide the power source. What will be the power source? It could be an engine, a tractor, or an electric DC motor. So, depending on that, we have to decide what should be the boom width? So, for tractor boom sprayers, usually the boom width varies from 6 to 15 meters long, and they are sectionalized and hinged so that you can fold them to make transportation easier. So, it will cover less width.

So, it all depends on what is the power source? Then, knowing the application rate of liquid chemicals, the nozzle operating pressure and discharge will be finalized. So, for a given crop, if you fix the application rate, the width, and the number of nozzles, then you try to find out what the discharge rate from each nozzle will be and at what pressure. So, that will be your operating pressure. So, once you know the operating pressure, then the total output of the nozzles will give you the discharge from the pump.

Again, one thing that has to be considered is: what kind of agitating system are we providing? If you are providing a hydraulic agitating system, then the discharge you get from the nozzles is not the discharge from the pump. You have to add the discharge required for carrying out hydraulic agitation. So, what we basically decide is: if it is a mechanical agitating system, then the pressure at which the nozzle is to be operated and the total discharge from the nozzle, that will be the desired pressure and discharge from the pump. Usually, the operating pressure varies from 275 to 690 kilo Pascals for applying to crops. And the spraying units are usually equipped with the centrifugal pump, gear pump, roller pump or diaphragm pump depending on the volume requirement. If you require more volume go for centrifugal pump, if you require lesser volume go for gear pumps or a diaphragm pumps or rotary roller pumps. Then once you decide the type of nozzle, number of nozzles, then pump capacity of course, pump capacity again depends on the type of agitating system, then comes the storage unit. What should be the storage unit? Usually the plastic tank is taken - polypropylene and the capacity of tank will be decided knowing the application rate, forward speed of travel, boom width, and the duration, duration for which you are going to carry out spraying at a stretch. So, usually the tank capacity varies from 0.2 to 1.9 meter cube, again it depends on the power source or what will be the power. Suppose, it is the DC motor you cannot go even up to 0.2 meter cube, you have to limit the tank capacity between 50 liters, 100 liter So, if it is a tractor drone this is the capacity, if it is a power trail drone then you can increase the capacity from say 100 liters to 150 liters that way. So, more the capacity lesser will be the refilling - number of refills and hence your unproductive time will reduce and your fuel efficiency will increase. But at the same time If you increase the tank capacity just to reduce the number of fills, then weight will increase and that will increase the rolling resistance that means, power required to propel the system forward.

Then comes the agitating system, there are two types of agitating systems you have to follow, either you follow mechanical agitating system or you have to follow hydraulic agitating system. So, the boundary line is 2.1 Mega Pascal, if the system pressure is around

that, then you prefer to have mechanical agitating system. If the pressure is lesser than that then go for hydraulic agitating system. So, if it is a hydraulic agitator system then we have to find out what is the discharge which is required to carry out agitation? and the same discharge for carrying out agitation has to be added to the discharge from the nozzles to find out the total discharge required from the pump. And the operating pressure will be the same as what we require at the nozzle. So, pressure is fixed, volume will change, and we also have to take into consideration some extra pressure, in the sense that the liquid flows from the pump to the nozzle through pipes, there will be losses. So, to account for the losses, we can increase the pressure a little bit - that means you can take an extra 10 per cent. So, that will be your design pressure and volume for pump selection.

Then, after deciding on the spraying unit, comes the storage tank and agitating system. Next is how you move the machine inside the field. So, we require some wheels to propel it. Once you provide wheels, there has to be a power transmission system and a clutch to disengage the power supply to the individual wheels because, when you are providing power to the wheels while taking a turn, we have to have some mechanism to disengage the power supply. So, we require a clutch system. And we require a transmission system because the RPM at which the engine is rotating, or the DC motor is rotating, or the tractor is moving - the same RPM is not required for rotating the pump or for propelling the wheels or powering the wheels. So, we have to have a transmission system.

The next important thing is the size of the wheels when you decide the size of wheels for a self-propelled sprayer. So, the first thing we should look into is what crops you are going to handle. So, what is the maximum height of the crops? You should take at least 20 to 25 centimeters of clearance so that it does not get damaged during spraying. So, once you decide the diameter of the wheel, then you find out the boom height. So, you have to make provisions so that you can vary the boom height because, if you want to make the spraying unit suitable for different crops, you have to make the boom height variable.

So, based on the size of the wheels, the power source, and the mode of operation, the transmission unit has to be decided, and the boom height has to be decided. Then, the power supply unit - as I said, it could be a tractor, a power tiller, an engine (diesel or petrol), or it could be a DC motor. So, the power requirement, as I mentioned, is needed for propelling and pumping. So, power is required for carrying out agitation. So, if it is a hydraulic agitation system, then we do not require any extra power for agitation because the same pump will be utilized. So, you only have to increase the capacity of the pump. If it is a mechanical agitation system, then you need extra power to rotate the paddles fitted inside

the tank. So, while deciding the power requirement, three things must be kept in mind: whether the agitation system is mechanical or hydraulic, the power should be sufficient to run the entire sprayer in the field, and it should be able to run the pump. So, these are the things one must keep in mind while designing the spraying unit.

Now, let us see how to develop an unmanned sprayer. So, the first thing, as I said, is to select the type of nozzle and pump to be used in the liquid chemical applicator. We have also developed an unmanned sprayer, and I will explain the procedure we followed. So, we first selected two types of nozzles: fan-type and hollow-cone type, and then carried out testing in the laboratory using a patternator. From this, we tried to determine - a 25 per cent overlap in the case of a fan-type nozzle would provide more or less uniform spraying. So, that is why we selected a fan-type nozzle. And then, the type of pump must be decided based on the operating pressure, discharge rate, and the number of nozzles to be fitted in the liquid chemical applicator.

Since the power source is solar energy as I said. So, initially we try to run it with a battery. That means, battery is the power source and the batteries are charged using the solar panels during the time of spraying. So, that is why it is called a solar energy operated sprayer. So, that means, our power source is mainly the battery. So, if you are going for battery then naturally you cannot go for a bigger boom width as I said 6 meter to 15 meter. So, we limited our boom width to say 6 nozzles, 6 nozzles with the spacing of 40 to 45 centimeters. So, that way 2.5 meter is the boom width we kept and then 6 nozzles output. Knowing the application rate we can find out what will be the output from each nozzle. So, we fix the total discharge from the nozzles. Then we - since the system pressure is low, we selected a hydraulic agitating system and the total discharge was computed and then finally, the pump was selected as a diaphragm pump which can, which can be operated by 80 Watt - it is coupled to a 80 Watt motor. And that is available in the market to supply this one. So, 6 nozzles with a spacing of 40-45 centimetre that is adjustable and then the pump is run by a 12 Volt 80 Watt pump. So, then we try to find out what will be the power source for the spraying unit - for propelling the spraying unit. So, we decided to provide three wheels. So, three wheels means front two wheels should be the powered wheels and the rear will be a towed wheel which will help in steering and supporting the total spraying unit.

So, we provided sufficient ground clearance. So, taking the crop height and ground and the clearance, we selected the tyre diameter as 710 millimeter. These are pneumatic wheels. And the rear wheel will be selected as a overall diameter of 360 millimeter. Then power - front wheels of the sprayer they are driven by a DC motor using chain and sprocket

connected to a common power shaft. Because once you transmit power we need to reduce because DC motor which is selected is of higher rpm.

So, we have to provide a transmission system. So, we provided a transmission system. And then we also provided a clutch. Dog clutches are provided to the two wheels. So that we can take a turn. At the end if you want to take a turn to the left or right you can utilize those clutches to disengage power. And that engagement and disengagement was possible by utilizing the actuators - linear actuators.

Then to make it unmanned we require a transceiver unit. So, transceiver unit means it comprises of a transmitter and a receiver. So, the transmitter and the receiver - transmitter will be with the operator and receiver will be in the sprayer. So, whatever data we send like forward speed or whether you want to switch on or switch off the pump or whether you want to engage or disengage the lever, all those information are to be sent to the receiver with the help of a microcontroller. And we have used a HC-12 transmission module. I will come to that little later what is that, how it looks like and what are the different units present. Then there should be a receiver unit as I said, it was kept on the vehicle that means, sprayer and it was connected to a microcontroller. The microcontroller waited for the receipt of data packets. Actually the data which are given in the form of packets. So that first what will do after successful receipt of the entire data packet, the microcontroller computed the control logic and sent the control signals to the corresponding drivers or the drivers of the actuators.

Initially the data packet which is received it has to be split into individual components and then the actuation happened simultaneously or sequentially and that is done by the microcontroller. So, you have to develop a control logic and the logic was developed to actuate these different components of liquid chemical applicator or sprayer we can say. So, that will first analyze the data which is received then it will give signals to the respective controllers to actuate.

Then the powering system, the powering system is required to supply power for propelling as well as spraying and the power for powering the liquid chemical applicator what we did is a solar photovoltaic system comprising flexible solar panels with a maximum power point tracker. So, that it will maximize the output from the solar panels. Then there are lead acid batteries and these were combined to supply power to the battery. So, initially the battery will be charged and the requirement is met that is current and voltage requirement

are met by taking power from the battery. So, you are not taking directly from the solar panels.

So, this is the CAD model of the unmanned sprayer which we developed As I said it has three wheels: front two wheels, then there is a rear wheel, which is a towed wheel, then this yellow one is the boom, then the nozzles are fitted at spacing, then the middle one is the tank - storage tank and pump is on the other side. So, this is the power transmission unit and batteries are kept at the back and then on the top there will be solar panel.

So, the specifications, as I said, the width of the boom is 300 centimeters, the ground clearance is 85 centimeters, and the height of the entire machine is 180 centimeters. And the nozzles, as I said, are 6 nozzles. These are all flat fan-type nozzles. The discharge is 0.56 plus or minus 0.07 liters per minute. So, it is covering an actual width of 3.39 meters. The spray angle was 89.35 degrees, the pump selected was a 12-Volt, 80-Watt, which gives a discharge of 9 liters per minute, and the cutoff pressure is 8 bar. Then, the propelling unit, as I said - the diameter of the front wheels is 71 centimeters, the diameter of the idle wheel is 47 centimeters, and it takes a radius - the turning radius is around 1.28 meters. The total weight is 148 kg, including the weight of the liquid. Since the tank has a 100-liter capacity, that means the rest of the weight is only 48 to 50 kg. Then, the maximum forward speed - so I have indicated the payload as 95 liters. The forward speed, which you obtained at maximum, is 1.88, but it is not always possible to move at 1.88 km per hour. So, you can control this with the help of a controller. Then, the solar panels selected are 160-Watt - 2 numbers. They are connected in series. Then there is an MPPT - Maximum Power Point Tracker. And the battery selected is a 24-volt, 14-ampere-hour - this is our requirement. So, to meet this requirement, we selected 4 numbers of 12-volt batteries with a 7-ampere-hour capacity. So, that way, they are connected in series and parallel to make a 24-Volt, 14-ampere-hour output. Then, the controlling unit, as I said dog clutch - it requires a linear actuator which consumes 24 Watts, 12-Volt, 24-Watt. The left side and right side both have the same linear actuators. So, 24-Watt, 12-Volt. Then, the steering. For steering—that means, for rotating the rear wheel - we require an actuator that requires 24-Volt, 96-Watt.

Then controllers - microcontrollers and sensors, they are consuming 10 Watt maximum and the range of wireless transceiver module is maximum up to 115 meter. So, this is the specification of the pump which we use - which is selected, then this is the transmission unit which is provided with dog clutch, this is the motor, this side there is dog clutch this one, this side there is - this is the power shaft, then power goes to this shaft, then shaft will send power to the wheel. For calculation of the - for deciding the pump, we know

application rate as 250 liter per hectare that we considered, then recommended discharge of 1 nozzle is 0.2083 liter per minute. So, 6 nozzles consume - require this much liter per minute. Then the recommended pressure was 300 kilo Pascal and part of the pump - pump discharge is diverted to the tank for hydraulic agitation.

So, we require around 0.2 liter per second. So, then power requirement we calculated. Taking pressure and discharge we calculated. This comes to 66.25 Watt and the market availability pump is 80 Watt. So, we selected that one. So, the specification is 12 volt 80 Watt and it is consuming a current of 6.6 Ampere.

So, for steering there are 6 possible combinations by which you can move forward or take a turn. So, first one is steering wheel for moving forward both the clutches are engaged and in the reverse side also both the clutches are engaged only the direction of power supply has to be changed so that motor will rotate in the other way. To take a turn to the left then left side clutch has to be disengaged and the toad wheel has to turn right just opposite to this one then we take a left turn. Now, for taking a reverse left turn same thing, but only the toad wheel has to be - the toad wheel means the steering wheel has to be rotated in the reverse direction that is the difference. Now, for taking a turn to the right, the right clutch has to be disengaged and the steering wheel has to be rotated to the left. So, there are altogether 6 combinations by which you can move forward, rearward or you can take left side turn or right side turn in forward direction or in backward direction. So, these are the possible steering facilities.

Then the transmitter that is the important component. We developed a transmitter which looks like this. This has a joystick by which you can if you press it forward it moves in the forward direction, if you press it in the rearward direction then it will move in the rearward direction. So, there will be a steering control knob which will rotate the steering wheel then there will be pump switch on and off that means, during turning we want to switch off the supply current - supply to the pump. So, that discharge is not there. So, there is a control here then this will indicate - then the micro controller here and then forward speed control knob. Suppose you want to increase or decrease the forward speed or the rearward speed you can do it by this knob. So, the transceiver it consisted of a wireless transmitter and a receiver of a HC12 wireless serial module of 433 Mega Hertz frequency. So, the transmitter continuously sends a stream of data packet at a specified or a predetermined time interval which we have taken as 250 millisecond. Then the transmitter was powered by 9 volt battery 600 milliampere hour and it can be easily carried by the user, it is a lighter in weight.

So, the number of things which are in the transmitter are wireless transmitter receiver, this is HC-12 wireless serial module, then there is a microcontroller, there is a joystick and display unit. A microcontroller present on the transmitter read all the input data first provided by the user through the knobs and buttons and then it bundles this data into serial data packet as shown in this figure. Then the data packet is transmitted continuously within a set time interval of 250 millisecond. So, whatever signals we give that has to be transmitted in bundles, then there will be receiver which will receive, then it will split into individual signals, then those signals will be read by microcontroller, then it will be sent to control logic, control logic will give necessary signals to actuate the respective instructions. So, the receiver is kept on the sprayer and it is connected to also a microcontroller and the microcontroller waits for the receipt of data packet and receives it upon the availability. After the successful receipt of entire data packet what is done is it will be split up into individual components and then the actuation happens simultaneously or sequentially by the microcontroller. The microcontroller will compute the control logic and it will send the signals to the corresponding drivers of the actuators by analyzing the input data received. So, this is the control logic where if you look at this first you have to initialize, initialize the control ports of the microcontroller. Then whatever data which is received that has to be decoded and then update the data packet values that mean x direction value, y direction value, propelling speed, pumped status value. Then there is the left side is whether you want to take a turn or not.

So, if you want to take a turn then this clutch to actuate the clutch this is the logic. Then for steering this is the right side logic is for steering. that means, to rotate the towed wheel which is present in the rear side. If you do not require turning that means, you do not require a clutch to be actuated. So, then we directly go to this unit, where it - the current will go to the motor to drive the two front wheels so that we can move forward or rearward. So, this side is for propelling in a straight way. So, if you are taking a turn after doing this again you have to come to this, this portion is for moving forward or rearward and this side is for pump status that means, whether you want to run the pump or not. So, this is the control logic which is divided into 4 segments initially the data input, then the data has to be verified whether you want to take a turn or not, if you want to take a turn then the clutch as well as the steering wheel has to be actuated, then you want to move forward or rearward that is in the this side and the right side is form status.

This table shows the power requirement for different components of the unmanned liquid sprayer. So, if you look at the propelling of the DC motor, it is consuming 264 Watts. We

have selected a motor of 450 Watts, a 24-Volt DC motor, but it is actually consuming 264 Watts because we are not getting this size of motor in the market. So, that is why the smallest size available in the market is selected. So, the pump requires 80 watts, which is 12 Volts and 7 Amperes. The dog clutch requires 12 Volts, 2 Amperes, and 24 Watts. Then, the steering linear actuator requires 24 Volts and 4 Amperes, so 96 watts. The microcontroller requires 10 Watts. So, altogether, we require a total power of 24 Volts and 14 Ampere-hours. That is our design calculation, and that will be sufficient to run this unit. So, once you decide the size of the battery, then we try to find out what is the ampere-hour requirement? Depending on the ampere-hour requirement, we have to select the solar panel size.

So, we decided - we have found that for calculating the size of the battery, we need to know the total watt-hours required per day. And days of autonomy - that means how much time you want to operate continuously - then the discharge rate of the battery, how much discharge we allow, and then the nominal battery voltage. So, those factors are taken into consideration. For propelling, we got 11.46 ampere-hours. Similarly, for linear actuators and for the dog clutch as well as the towed wheel, we got 5.21 ampere-hours. So, taking this into consideration, the total energy consumption is known, and what is the peak sunshine hours available in our locality? That comes to 4.5 hours. So, we require autonomy of 3 hours. So, the total watt-hours are divided by the peak sunshine hours per day, and that will give you the solar panel size. So, we took two flexible solar panels of 160 Watts peak, so that they can supply the necessary current to charge the battery during operation. These are the specifications, as I said: rated power is 160 Watts, open-circuit voltage is 21.6 Volts, short-circuit current is 9.8 Amperes, and the maximum voltage and maximum current are 17.6 Volts and 9.9 Amperes. So, this is connected to the MPPT, so that the MPPT will try to maximize the output either by increasing the voltage or increasing the current.

Then this is the finally developed liquid chemical applicator and these are different views, where you can see the haziness that means, that indicate that the developed solar energy operated sprayer could be utilized for spraying. You can see the boom. On the boom you can see nozzles are mounted. So, the speed which we actually tested in the field is varying from 0.8 to 2 kilometer per hour and time taken to actuate the dog clutch is 3.5 seconds and the turning radius is 1.73 meter. Field capacity varies depending on the speed at which you are going to move.

So, I will show you a video where it is operated you can see the unmanned solar energy operated sprayer is moving. Now, it will take a turn. So, the steering wheel is rotating at

the rear, the rear towed wheel you can see the rear towed wheel is rotated. It will take a turn to the right. So, the steering wheel is rotated to the left. Now again the steering wheel will be straightened. Now it is straightening and the motor switch is on. The spray is going on now it will start moving forward. So that means, all the components which we designed are working nicely. Then we wanted to show the forward and reverse movements in the grassy land. So, you can see very clearly how the spraying is going on. Now, we will move it backward. So, this is how we developed following the design aspects we discussed. And then we finally developed and tested it in the field.

These are the references and this is the conclusion. We designed the self-propelled sprayer based on the discussion I made, and that helped us to develop that solar energy-operated sprayer. We tried it in the field, and it was working. It was working for a period of, say - without charging the battery, when the battery is fully charged, it can operate for 40 to 45 minutes. And to charge the battery during operation, we can continuously run it for 2 to 2.5 hours. That means there will be simultaneous charging and operation of this sprayer. That's all.

Thank you.