DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCE

DESIGN OF AUTONOMOUS VEHICLE FOR GREENHOUSES

by
Seçkin BİLDİK

July, 2013
İZMİR

DESIGN OF AUTONOMOUS VEHICLE FOR GREENHOUSES

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M.Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"DESIGN OF AUTONOMOUS VEHICLE FOR GREENHOUSES"** completed by **SEÇKİN BİLDİK** under supervision of **ASSIST. PROF. DR. LEVENT MALGACA** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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DESIGN OF AUTONOMOUS VEHICLE FOR GREENHOUSES

ABSTRACT

The aim of this thesis is to produce a prototype mobile vehicle that can apply pesticides automatically in greenhouses. The vehicle consists of a chassis, rail wheels, removable pesticide tank, a battery and a pesticide spraying system. Vehicle velocity, energy consumption, pesticide spraying pressure are the significant design parameters. The vehicle is driven with a DC motor and required power is provided by the battery system. The pesticide spraying system and a small tank are located on top of the vehicle. The small tank is filled by pumping the fluid from the main tank where is in the hall. The vehicle moves along two pipelines, which are placed on the ground and also used for heating. After the vehicle is placed on the row, it sprays the pesticide by moving automatically with the small tank. The following automated movement is fulfilled through the connected sensors. Systematic movement of the vehicle inside the greenhouse starts after it is located on the line, in which the plants exist, and the movement covers a course until the end of the corridor and a comeback.

The design and the assembly of all vehicle parts have been carried out in SolidWorks software. CosmosWorks, ANSYS and CosmosMotion software have been used for the machinery dynamics, static and frequency analyses. According to the analysis results, driving system has been chosen, and the thickness of the vehicle body and chassis have been determined. The final design has been obtained by evaluating the analyses results and optimizing the predesign.

Production process has been started after design work. The control program has been integrated after completing the assembly of the vehicle. Automated movement of the vehicle has been achieved through inductive distance sensors and PLC unit. Both the velocity of the vehicle and the distance can be programmed, moreover the spraying pressure can be regulated. The pesticide spraying tests of the prototype vehicle has been successfully conducted in the Agrobay Greenhouse, Izmir-Dikili.

Keywords : Static analysis, vehicle design, automatic spraying, greenhouse

DESIGN OF AUTONOMOUS VEHICLE FOR GREENHOUSES

ÖZ

Bu çalışmada, seralarda otomatik ilaçlama yapan bir mobil aracın tasarımı ve prototip üretiminin gerçekleştirilmesidir. Araç taşıyıcı bir gövde, ray tekerler, taşınabilir ilaç deposu, akü, ve ilaç püskürtme sisteminden oluşmaktadır. Araç hızı, enerji tüketimi, ilaç püskürtme basıncı, önemli tasarım parametreleridir. Araç bir DC motor ile sürülür, enerjisini de bir akü sisteminden alır. Araç üzerinde ilaç püskürtme sistemi, küçük bir tank bulunur. Küçük tank ana koridordaki büyük tanktan pompalanarak doldurulur. Araç hareketini, zemine döşenmiş olan ve ısıtma amaçlı olarak da kullanılan iki boru hattı üzerinde gerçekleştirir. Araç sıra üzerine bırakıldıktan sonra üzerindeki küçük tank ile otomatik olarak hareket ederek ilaç püskürtme işlemini gerçekleştirir. Aracın sıradaki otomatik hareketi araca bağlanan algılayıcılar ile sağlanır. Aracın sera içerisindeki sistematik hareketi bitkilerin bulunduğu hatta bırakıldıktan sonra başlar ve o koridorun en uç noktasına gidiş, geri-geliş şeklinde tanımlanır.

Aracın tüm parçaları SolidWorks programında modellenerek montajı oluşturulmuştur. Makine dinamiği, statik ve frekans analizleri için CosmosWorks, ANSYS ve CosmosMotion programları kullanılmıştır. Analiz sonuçlarına dayalı tahrik sistemi seçilmiştir, araç gövdesi ve taşıyıcı sistemin kalınlıkları belirlenmiştir. Elde edilen sonuçlar değerlendirilerek ve tasarım optimize edilerek son tasarıma ulaşılmıştır.

Tasarım çalışmaları tamamlanmasından sonra üretime geçilmiştir. Aracın mekanik montajı tamamlandıktan sonra kontrol programı entegre edilmiştir. Aracın otomatik hareketi, indüktif, mesafe algılayıcılar ve PLC kontrolcü ile sağlanmıştır. Aracın hızı ve mesafe programlanabilir, aynı zamanda ilaçlama basıncı ayarlanabilirdir. Prototip aracın ilaçlama testleri Agrobay Seracılık İzmir-Dikili tesislerinde başarıyla gerçekleştirilmiştir.

Anahtar Sözcükler: Statik analiz, araç tasarımı, otomatik ilaçlama, sera

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CHAPTER ONE
INTRODUCTION

A vehicle which senses its environment with lidar, sensor, radar, etc., and navigates without human control**,** is called Autonomous Vehicle also known as a Robotic Car. Basically autonomous vehicle is defined as a vehicle that moves by itself.

1.1 History

The early autonomous car, which was sponsored by General Motors, was represented by Norman Bel Geddes in 1939. It was working with electricity and navigated by radio.

But the first known autonomous vehicle was developed in Japan by Tsukuba Mechanical Engineering Laboratory, in 1977. It was following street markers with 20 mph.

In 1980's, the vehicle that Mercedes-Benz Project, which the work of Ernst Dickmanss, achieved 63 km/h. Afterwards DARPA (The Defense Advanced Research Projects Agency) developed a vehicle, which had the first off-road map and laser sensors.

With the success of the projects, between 1987 and 1995 Pan-Europen worked on the largest autonomous vehicle project which is called "Prometheus".

In 1990's, CMU Navlab, "No hands Across America Project" and AHS Demo'97 events happened.

Also in 2000's was developed projects were developed like a Carsense ASHRA Demo 2000, Chameleon, DARPA Demo III, ARCOS(Research Action for Secure

Driving), Cartalk 2000, INVENT (Intelligent traffic and user-oriented technology), PREVENT, DARPA Grand Challenge III.

In consideration of these experiences, autonomous vehicle system applications was started to be used in many working areas such as military, greenhouses, logistic, aerospace industries.

Figure 1.1 Autonomous vehicles in different industries

1.2 Design an Autonomous Vehicle

In order to fulfill the requirements for an autonomous behavior, the following features are significant:

Mobility: The ability to reach the specified location inside the operational environment.

Adaptivity: As the vehicle may operate in a dynamic environment, it can face unpredicted situations. Therefore it should have the capability to adapt those without hindering its task.

Perception: Gathering the information from the operational environment is essential for a precise navigation and task fulfillment.

Interaction ability: The vehicle should get the commands and tasks from the operator correctly so that it can accomplish them. Therefore, a solid interaction between the operator or control unit and the vehicle is a key factor.

Safety: The vehicle shouldn't damage any objects or surroundings within the operational environment. The simplest way to accomplish this feature is to use an emergency stop and a feedback system for the detection of dangerous situations.

There are several points that need to be considered in the design of autonomous vehicles. Firstly, the modeling of the kinematics and dynamics should be handled in a way that the vehicle can reach the desired location without failure. Second point is the navigation of the robot. In order to accomplish that, sensors and fusion algorithms are used to retrieve the information from the environment. After that, the gathered information is used in integrated algorithms such as obstacle avoidance, emergency stop, goal point and etc. Finally, the localization of the vehicle should be accomplished. It means that the vehicle should know where it is, so that it can move along a predefined path and achieve the tasks.

1.3 Control of the Autonomous Vehicle

The architecture of a control system is determined according to the tasks and environment; therefore it has numerous possible variations. The control systems can also have complex algorithms depending on the demands and the environment. A control structure generally has one or more of the following components and functionalities in order to fulfill the desired tasks.

Motor controller: A controller is integrated in order to obtain the required velocity and acceleration.

Navigation: This functionality allows the vehicle to know the surroundings, obstacles and its own location within the operational environment.

User interaction: A suitable human-machine interface should be set up in order to transmit the required tasks and receive feedback from the vehicle.

Planning function: This function informs the vehicle about its goal point and the track it should follow to reach the desired location.

The most important part of the control at the autonomous vehicles is the sensors. The sensors are also grouped according to their perception and operating specifications. Sensors that are widely used in autonomous vehicles are:

Tactile sensors: The detection is accomplished by the contact between the object and an obstacle.

Pose measurement sensors: The techniques used in these sensors are based on landmarks and inclinometers.

Sensors for inertial systems: The velocity can be determined by measuring the accelerations and turning rates. The advantage of these sensors is that they are not affected by any disturbance from the outer environment.

Distance sensors: They are used in collision avoidance and mapping tasks, therefore significant for an autonomous vehicle. This type includes infrared, ultrasonic, laser and vision sensors.

In this thesis, we worked on the design of a special autonomous vehicle which sprayed plants in greenhouses.

1.4 Greenhouses

Greenhouses are buildings which are covered with different materials for growing plants. Plastic or glass is the used material because of sun absorption by plants. In addition, for trapping the energy inside, the heating systems are built. And also automatic cooling and air systems work for stabilization of the temperature.

In greenhouse, the main corridor which is used for transportation and working space is called *hall*. And the corridor, which is between the plants, is called *row* as shown below in Figure 1.2. One side of the hall, between two poles, which feature six rows, is called *tunnel*.

Figure 1.2 Form of Greenhouse

And systems are positioned as seen in Figure 1.3.

Figure 1.3 Systems in Greenhouse

Greenhouses are ideal for greater control over the growth of the plants and delivering every fruit and vegetable in every season. So nowadays, number of the greenhouses is increasing and with this increment, the requirement of the automation systems is increasing too. The increase of the human population in the greenhouses is triggering the chance of the disease therefore; especially unmanned vehicles are given preference.

1.5 Vehicles in Greenhouse

Transportation cart (trolley): After harvesting crop; vegetables, fruits and flowers are carted by these vehicles.

Figure 1.4 Automatic and manual transportation vehicle

Pipe rail cart (trolley): These vehicles are used for cultivation, harvest and application of pesticide. With the special wheels, they work on the heating pipe and move on the hall.

Figure 1.5 Harvest and pesticide vehicle

Applying pesticide is the most important execution in the greenhouses. According to disease average three days in a week, disinfectant is applied to the plants. At the present time, employees and semi-automatic vehicles perform the applications. But these applications are not stabile and productive because of the human factor. Thus, automation and unmanned applications must be generalized.

At first, for designing an autonomous spray trolley, present vehicles must be examined.

1.5.1 Pipe Rail Spray Trolley

Present vehicles consist of a body, a boom, an electrical panel and hose reel and they are shown in Figure 1.6. Detailed part of the trolley can be seen in Figure 1.7.

A motor, gears, wheels, chassis and production parts are involved in the body. Body is the main and moving part of the vehicle. Boom is the spraying part of the vehicle. It has the nozzles which is a module to spray the plants.

Hose reel provide the water - pesticide mix from the main tank to the boom. While vehicle is moving, it must be synchronized with the motor for controlling the tension of the hose. To the forward, it releases the hose, to the backward it picks up the hose.

Electrical panel is the brain of the vehicle. Motor drive, PLC and fuses are involved this part. It controls every movement in the vehicle. Therefore it is called control panel, too.

Figure 1.6 Main part of the spray trolley (IDM Product)

1	Spray boom	11	Glass wall (end) spray nozzle
2	Control panel	12	Pressure meter
3	Charge plug	13	Manual shutter
4	Lift system (lever)	14	Press filter
5	Hose reel	15	Stop bumper (front)
6	Hose guide	16	Battery chamber
7	Steel flange roll (counting roll)	17	Hose
8	Pipe rail detection	18	Stop bumper (rear)
9	Drive roll (front side Meto)	19	Pipe rail guidance
10	Side spray nozzle		

Figure 1.7 Detailed parts (METO user manual)

At the present time two types of spray trolleys are being used. All of them have body, boom and hose reel. But first, the simpler trolley is being driven by the operator who stands space between boom and hose reel. Second type of trolley moves on the heating pipes unmanned. While spraying, operator stands on the hall to put it from one row to another. Control between rows on the hall is done manually. On the hall, the first trolley's control is done manually, too.

An example from main specifications of two types from Stolze and Berg Product is shown below in Table 1.1

Table 1.1 Main specifications (User manual values)

		
	First Type	**Second Type**
Height x Length x Width (mm)	2381 x 1500 x 663	1725 x 1428 x 104
Max Hose Pressure (Bar)	40	40
Weight (kg)	220	335
Motor (kW)	0.37 (24 V Dc)	0.37(24 V Dc)
Max Speed (m/min)	60	70
Batteries (Ah)	110	110

1.6 Previous Studies

A summary about the robotic applications related with greenhouse automation and indoor operating vehicles is introduced in this chapter. In the first literature, a robotic system which monitories the growing health, picks up samples, sprays locally, detects harmful chemical residuals is designed (G.M. Acaccia & R.C. Michelini & others, 2003). A robust and cost efficient mobile vehicle with a vision camera for greenhouse applications is introduced in the other literature (Mandow & J. M. Gómez-de-Gabriel & others, 1996). In that time control system supports autonomous navigation and shared human control. Buemi F. & Magrassi M. & others (1994) designed a 6 degree of freedom mobile robot with an image processor for land preparation. In other literature; the motion control of the autonomous vehicles, those operate in greenhouses, is evaluated related to the control of an indoor operating autonomous robot (F. Cuesta & A. Ollero & others, 2003). Their work on a new method to compute fuzzy perception of the environment is presented. Depending on that, sensors, those assist the motion of the vehicle, the interaction of the vehicle with the environment and its localization, are used considering the kinematic constraints of vehicles which are driven with two wheels.

In initial greenhouse robot applications, the problem of robot movement and sensor has been solved with mechanization, due to that; binary sensors for proximity and control have been used. Because of the developed technology, the increased durability and sensitivity of the sensors; vision systems can be used for both orientation (A.R. Jimenez & R. Ceres & J.L. Pons, 1911,1920,2000) and harvesting (Kanae Tanigaki & Tateshi Fujiura, 2008). Harvesting has been done by a shaker with the camera. In other literature (William Travis, & Adam T. Simmons & David M. Bevly, 2005) the vehicle control with lidar vision systems in indoor halls is explained. Another autonomous vehicle in greenhouses which moves through the crop lines has been produced. It has been called Fitorobot. (Julián Sánchez-Hermosilla & Francisco Rodríguez & others, 2006). Other vehicle had a six wheeler differential steering and fuzzy logic based proportional – derivative control system (Satnam Singh, 2004).

While doing this project, designer has a solid background in robot control, integrated design and analysis. Computer aided engineering, analysis knowledge and the background, which are introduced in these literatures, will be applied to the proposed work.

In the market research, information about two national and two international companies which produce spraying vehicles, have been gathered. Meto spray model of the Berg Product (www.bergproduct.com) which is manufactured in overseas. It has a hose reel system. The Wanjet S55 type of Wanjet company which has s tank system (www.wanjet.se) and the automated spraying vehicle with hose reel, which is produced domestically by Seraymak (www.seraymak.com) company , have been examined.

In this study, a vehicle which moved on the pipe rail automatically has been designed. The vehicle is driven with a DC motor and gets the required power from the battery system. The pesticide spraying system and a small tank are located on top of the vehicle. A Pump is used by the spraying system. Vehicle sprays the pesticide by moving automatically with the small tank. Automation is controlled by PLC. Automated movement is fulfilled through the connected sensors. Systematic movement of the vehicle inside the greenhouse starts after it is located on the row. The movement between the rows is directed by an operator by using the caster wheels.

CHAPTER TWO
DESIGN OF THE VEHICLE

Design of a vehicle is split into three main sections. First, research and development, second pre-design, finally production design. Design process includes following steps :

- Concept sketching
- Scale model
- Computer aided design
- Manufacturing process

Before the machine design at first, the purpose for the usage of machine should be clarified exactly. Using field, working area and ambient specifications, suitability of the outputs of machine and market research should be clarified at the first step.

After these conditions are clarified, free hand drawings of the machine can be the first step of the machine design. At this time also doing simple calculations about inputs and outputs of the machine can be very useful for future steps of the design. Then, detailed design of the machine can be started Nowadays CAD programs, which are used for creating solid models, are very useful for designers to shorten the design time and they also provide the chance to make detailed design and drawing different from the 2D drawing with hand, so the little mistakes has been mostly eliminated. At that time, also the cost analysis should be done and with these calculations, financial problems, which occur at later stages have been prevented. Also another point is manufacturing ways of the parts. They should be simple, cheap and allow an easy assembly. When designers start to design, they should consider proper functioning, cost of the machine, ease of the manufacturing, assembly, service, strength and rigidness of the parts.

After the first design step is done, necessary calculation should be done. At this point, designers use finite element analysis (FEA) programs to calculate and analyze to machine for easy, fast and reliable analysis procedure. FEA programs can do static, modal, dynamic, heat etc. analysis easily and results are more reliable, besides a shorter time is needed for calculations.

The results should be investigated very closely and based on the results, optimization process starts. After the improprieties of the design are solved, manufacturing and assembling starts. When assembling is finished, necessary tests should be done to find out whether the proper functioning is established.

For the best design, the problems of the available products and customer needs should be known. For this reason, a lot of greenhouse visits have been done. Received data from these visits is listed below:

- Humans must not stand on the vehicle while spraying. For not using a protector mask and clothes while moving with the trolley, most of the employees are affected by pesticide which is very harmful for the human health.
- Hose reel is a major problem in the greenhouse. Inattention of the employee can cause a broken and split hose. Therefore; a pump and a small tank, which has water and pesticide mix in it, can be used on the vehicle.
- Selected pump must provide water with a flow of 12 lt/min at 10 bar (minimum value) at the inflow of the nozzles. Flow rate and pressure value is be controllable.
- Tank capacity can be between 120 and 200 lt. Average of 12 liter mixed fluid is used for one row.
- Moving the vehicle from one row to another must be easy.
- Control panel screen must be easily understandable and usable. Speed values and timers should be controllable from the screen.
- While trolley is moving forward, spraying system does not work. Moving backward starts spraying and trolley speed must be constant. Thus, for saving time, it can move forward with high speed.
- In spite of breaking down the automatic system, a manual system can be added.
- Gel batteries are more efficient than dry batteries.

- It must have strength against the impact and can have a bumper for a stop at end of the pipe rail.

According to data, market parts are selected roughly and main parts of the vehicle are defined. Pre-design is modeled for analysis with SolidWorks as shown in Figure 2.1. Main parts are formed by tank for pesticide, boom for spraying, wheels, motor, chassis, cases for batteries and panel.

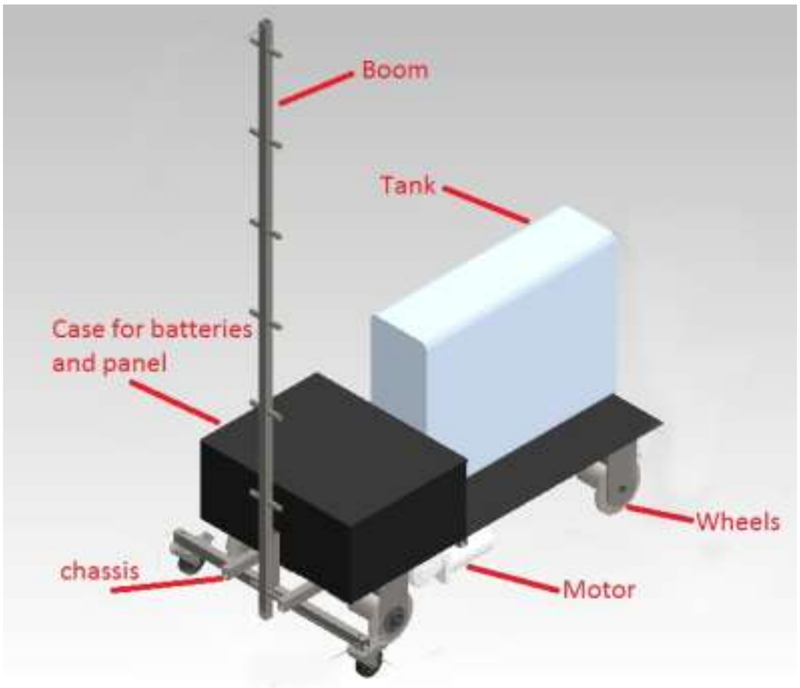


Figure 2.1 Pre-design of the vehicle

So far, pre design production parts are modeled. Market and production parts, images, specs, 3D drawings are given at appendix.

This project has been prosecuted with a commercial company. Hence, technical drawings of the production parts can't be given in this study due to the copyright law.

2.1 Market Parts

These parts are prepared parts at the markets. However, stock and supply of these parts are the most important properties. After selection, 3D models of the parts are being modeled with SolidWorks.

Market parts of the vehicle and main specifications are as given below:

Motor - 24 V DC, 750 W motor is selected. Reduction ratio is 1/32. It has an arm to separate axle from the reduction for moving the vehicle manually. Motor specifcaitons and test diagram are given at Appendix, in Figure 7.1 and 7.2.

Bearing units - Two type of bearing units are selected as pillow block housing and two bolt flange housing according to static analysis.

Pin - 6x6x16 pin has been selected.

Gears and chain - 3/8 "06B1 chain and gears are selected. For motor gear which had 55 number of teeth; for wheel axle gear which had 14 number of teeth are selected.

Caster – Casters have 160 kg load capacity for 125 wheel diameter.

Housing properties:

- Made of pressed steel, zinc-chromatized
- Double ball bearing swivel head
- Dust guard
- Wheel axle with nut and screw

Wheel properties:

- Wheel center with polyamide
- Polyurethane tread
- Without thread guards
- Plain bore, ball or roller bearing

Pump - Pump works with 24 V and at 20 bar gives max flow rate, 13 l/min. Pump properties are given at Appendix, in Figure 7.3.

Battery - 80 Ah deep cycle gel battery is selected. Its approx. weight is 27 kg. Battery properties are given at Appendix, in Figure 7.4. And general features are as given below:

- Silica gel technology for longer cycle life and better performance at cold ambient temperatures
- Special sheet separator and colloidal or foamed silica
- Deep discharge cycle increased by %50 as compared with the AGM battery
- High reliability and quality
- Excellent recovery from deep discharge
- Living up prevailing standards

Drawer Runners - Ball bearing drawer runners are used for changing battery case. General features are as given below:

- Carrying capacity : 160 kg
- Material : Stainless steel
- Locked system to hold close

Gas Spring - Gas spring is used between casters and chassis to reduce the crash strength when vehicle comes towards to hall from the pipe rails. Properties of the Gas Spring are given below:

- *Force* : 1200 N
- *Stroke* : 305 mm

Pipe Wheels - Pipe wheels are designed for driving on the heating pipes. So it resists to the high temperature and has two ball bearings for housing.

Handle, Hinge and Trekslot - Handle, hinge and trekslot are used on the plate and battery case. And materials for the parts are brass.

Tank - The tank is produced by polyethylene material as 150 liter capacity.

Nozzle - Nozzle has a teejet module, filter with teejet which has the code TP8002VK. Teejets are used for directed applications in air spraying, orchards and vineyards and other specialty crops. Also they are well-suited for applications of insecticides, fungicides, defoliants and foliar fertilizers at pressures of 40 PSI (3 bar) and above. Teejet flow rate – pressure chart is given at Appendix, in Figure 7.5.

Sensors – Three types of the sensors are used.

- **Distance sensor** – measures distance up to 10 m. It has wide operating temperature range -30 ˚C to +65 ˚C and 15x15 mm spot size.
- **Mechanical sensor** – has one analog output and works as an on-off system. When the switch moves, contact is opened and signal goes to the PLC.
- **Level sensor** – has one analog output and works as on-off system, too. When liquid level on the tank goes down, contact opens and signal goes to the PLC.

2.2 Production Parts

For the design of the production parts, design parameters must be defined. Position of the market parts, working area, use field, production simplicity, strength and material properties are the parameters for modeling.

While designing, lighter and simple parts are modeled. Because of the corrosion and vibration, mostly welded joints are used instead of the bolt and screw joint.

Material of all the parts is AISI 1020 and uses oven-drying. Only boom is made of stainless steel, because of the water flout on it. CNC, laser cut, welding are used for production.

Bar plate - links chassis and drawer runners

Battery case cap – protects batteries from external factor.

Battery case plate – slides with drawer runners and carries the battery case

Battery case – has batteries inside.

Boom – is the sparing part of the vehicle. Pesticide flow is in it.

Caster House – caster profile moves in this part.

Caster opposite house – gas spring attaches from one side in this part.

Caster profile – has the casters and gas spring attaches from other side with its mount.

Chassis – is main part of the vehicle. Every part links with each other and chassis.

Chassis table – is put on the chassis to protect the bottom of the vehicle.

Front axle house – houses the front axle from the outside.

Front axle – carries the front wheels.

Front wheel spacer – keeps the distance between wheels

Hinge pin – is the connection of caster profile between caster house and hinge between ladder. Caster profile and ladder are oscillated around this part.

Ladder hinge – links ladder to the chassis.

Ladder table – has a platform for standing on it.

Ladder – carries operator when vehicle is driven manually.

Motor plate – protects motor from the crash.

Motor ring – is put between gear and motor.

Motor turnbuckle plate – used for housing and turnbuckle of motor.

Panel flexible beam – panel is attached to the chassis by this part.

Rear axle house - houses the rear axle from the outside with bearing unit which is on it.

Rear axle – has driven gear and wheels.

Rear wheel spacer – keeps the distance between wheels

Tank chassis – pesticide tank is put over this part.

Drive wheel flange – provides to turn the gear and axle together

Wheel flange - provides to turn the wheel and axle together.

Sensor plate – distance sensor is linked to the chassis by this part.

2.3 Vehicle Overview

Figure 2.2 CAD model of the trolley

CAD model of the vehicle is seen in Figure 2.2

Autonomous motion is provided by 24 V DC motor and vehicle moves on heating pipes automatically without operator by special pipe rail wheels.

The motion between the rows is directed by an operator by using the caster wheels which are located at the rear of driving wheels from the handle over the control panel. In case of system malfunction, a separate system has been developed in order to allow a manual usage, in which an operator can use the ladder that leads through the rear side of the vehicle.

Spraying is applied with a 150 lt. tank and a pressure-flow controlled pump. Vehicle can spray average of 12 rows with full tank. Spraying system has a 2.3 m boom which has a modifiable position with 14 nozzles which have position controlled teejet heads. Vehicle can spray 10.000 m when batteries are fully charged. It is preferred for quality pesticide spraying and human health.

Vehicle has been controlled by PLC and motor has been driven by a motor driver. The velocity of the vehicle can be controlled by entering the velocity and stand-by timing to the control panel screen.

Vehicle general properties are as shown below in Table 2.1.

Table 2.1 SR-01 Automatic greenhouse spraying vehicle properties

Length x Width (mm)	1500 x 850
Pump (Bar – lt/m)	10 - 14
Weight (kg)	220 (Tank empty)
Motor (kW)	0.75 (24 V DC)
Max Speed (m/s)	1.8
Batteries (Ah)	80
Tank (lt)	150
Boom	2360 mm – 14 nozzles

And real image of the vehicle is given in Figure 2.3.

Figure 2.3 An image of the vehicle

CHAPTER THREE

INTEGRATED DESIGN AND ANALYSIS

Integrated design and analysis of the autonomous vehicle in this study is shown in Figure 3.1. This chart explains the process of the production design.

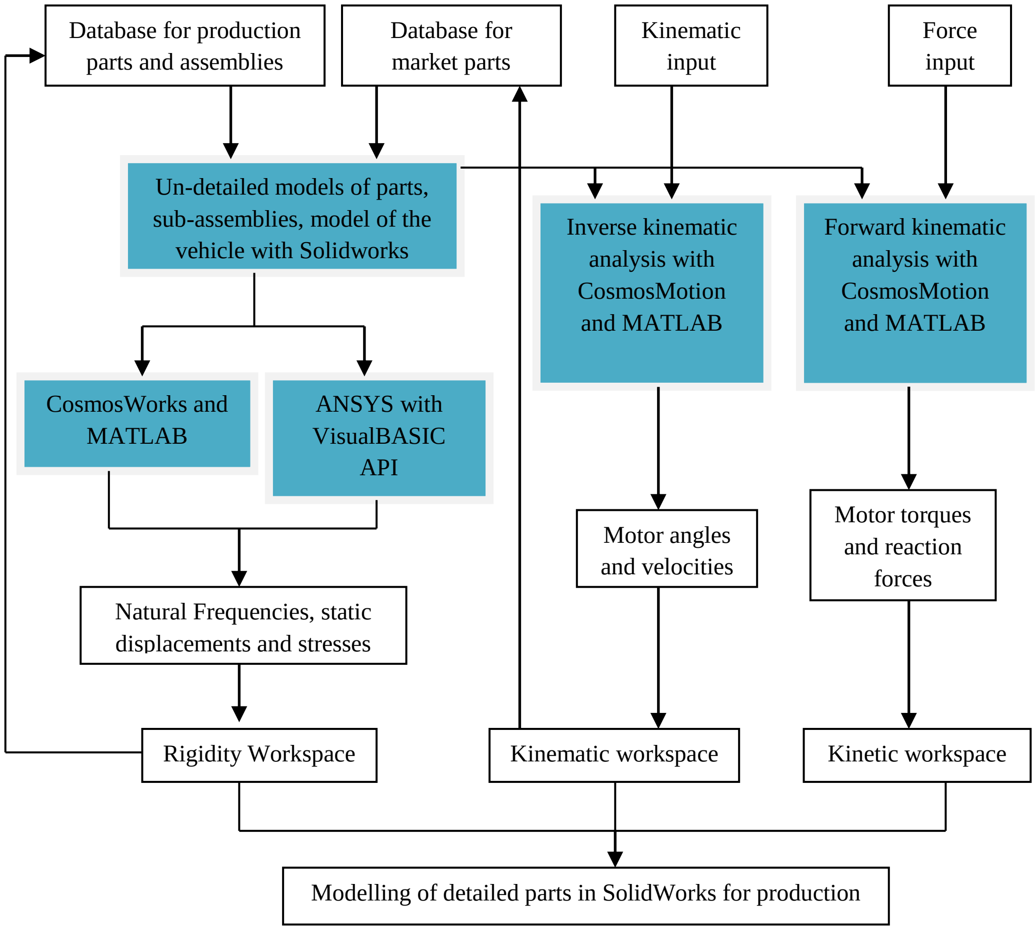


Figure 3.1 Flow chart of integrated design process

3.1 Flow Chart of Design and Analysis

By the means of databases un-detailed models has been designed. Market parts have been indicated and solid parts have been modeled. After modeling of the production parts and assemblies, dimensions and locations have been transferred to ANSYS with VisualBasic API. Natural frequencies, stresses have been calculated with ANSYS analysis.

Moreover, solid model of the vehicle has been exported to CosmosWorks and natural frequencies, stresses and displacements have been calculated again. And these results have been compared with ANSYS results.

On the other hand for selecting the motor ,which is the important part of the vehicle, be used inverse and forward kinematics with CosmosMotion.

In order to analyze forward and inverse kinematics, determinated velocity form has been entered and motor torque, and power consumption have been calculated. With these outputs, when start and end points have been entered with the travel time of the vehicle, velocities and displacements have been found.

Finally with the basic dynamic and static formulas these values have been calculated again and compared with each other.

According to the results, market parts have been selected from catalogues and production parts have been designed in detail considering to dynamic and static strength by the SolidWorks.

3.2 Simulation Model Design

For meshing process models must be undetailed. Hence, necessary features as holes, radiuses, bolts and screws etc. have been deleted from the parts and model has been suitable for design as seen in Figure 3.2.

First of all; FEA models have been designed for main parts as chassis, tank, battery case, panel and boom. Mass properties have been applied same as detailed model according to center of mass, weight and dimensions. Finally, all parts have been assembled .

Parts have been designed according to real part’s geometry and same materials have been applied. When reduced mass method has been applied, parts have been combined with each other. Applied forces have been calculated and boundary conditions have been determined.

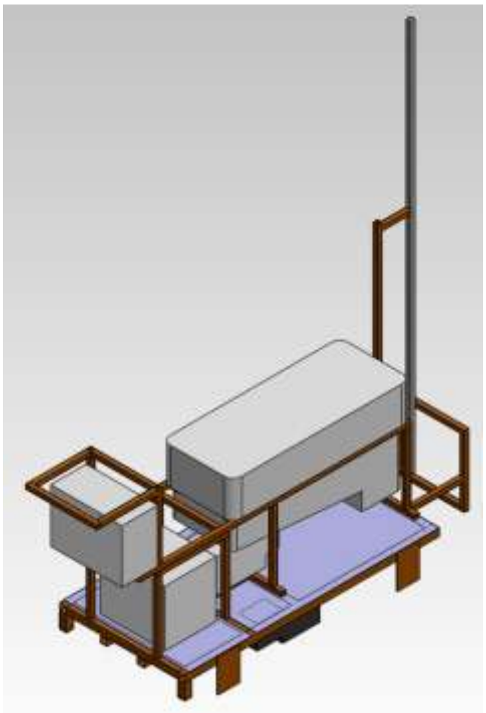


Figure 3.2 Simulation model of the vehicle

During the simulation, three types of software have been used. Basic information about the analysis programs are given below:

CosmosWorks - is an implementation of FEA (Finite Element Analysis), such as the analysis of stresses, deformations, natural frequencies, buckling etc.

In this study, static and natural frequency analysis of the CosmosWorks have been run for the whole vehicle and carrier parts of the vehicle as chassis, tank chassis, axles etc. Static analysis boundary conditions have been selected by the real world, and reaction forces have been calculated.

Simulations have been done with *h-adaptive* method and *direct sparse solver*. Concept of h-adaptive method has been to use smaller elements in regions with high errors. After running the study and estimating errors, the software automatically refines the mesh where an improvement in the results is needed . Direct sparse solver uses the Lagrange multiplier, this is a much better method and solves the equations directly.

For meshing maximum element, mesh type has been set to mixed type and standard mesh parameters has been input. Parts have been meshed with 30 mm global size and 1.5 mm tolerance.

Also, first order tetrahedral element which had total 12 DOFs (4 nodes with 3 DOFs at each node) has been selected as given in Figure 3.3. This element has straight edges and flat faces. After deformation, the edges and faces must retain these properties.

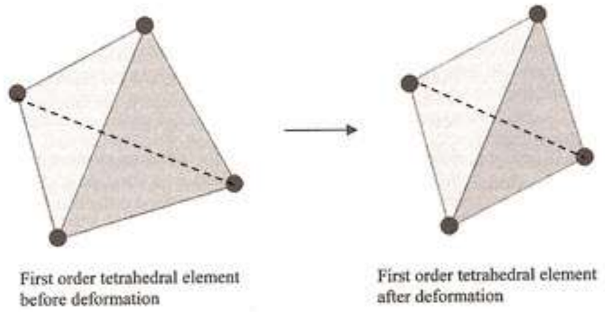


Figure 3.3 Jacobiant type (Engineering Analysis with Solidworks Simulation 2012, Paul M. Krowski)

ANSYS - is a general purpose software, used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers.

In this study, ANSYS beam analysis has been used with Visual Basic API. First location of points have been texted to the notepad as x,y,z coordinate. And material properties, masses, initial conditions have been texted too. With Visual Basic supported program data has been transferred to the SolidWorks as beam and assigned mass part. After control of the assembly in the SolidWorks, inputs have been opened with program at the ANSYS.

CosmosMotion - is software for evaluating the mechanical performance through operational movements using rigid body motion analysis.

In this study it has been used for time history of power consumption and motor torque.

3.3 Static Analysis

For static analysis, boundary conditions must be selected according to the real world firstly. Then reaction forces over the part and applied area of the forces have been defined. While static analysis, analysis inputs like boundary conditions, forces etc. have been stable.

According to analysis model of the vehicle weight, dimensions, center of mass have been obtained from the SolidWorks model properties and reaction forces have been calculated with general static force equations (3.2) and moment equations (3.1) have been given as Figure 3.4 and Figure 3.5.

$$\sum F_x = 0, \sum F_y = 0 \tag{3.1}$$

$$\sum M = 0$$

$$F_1 \times x_1 + F_2 \times x_2 + \cdots = 0 \tag{3.2}$$

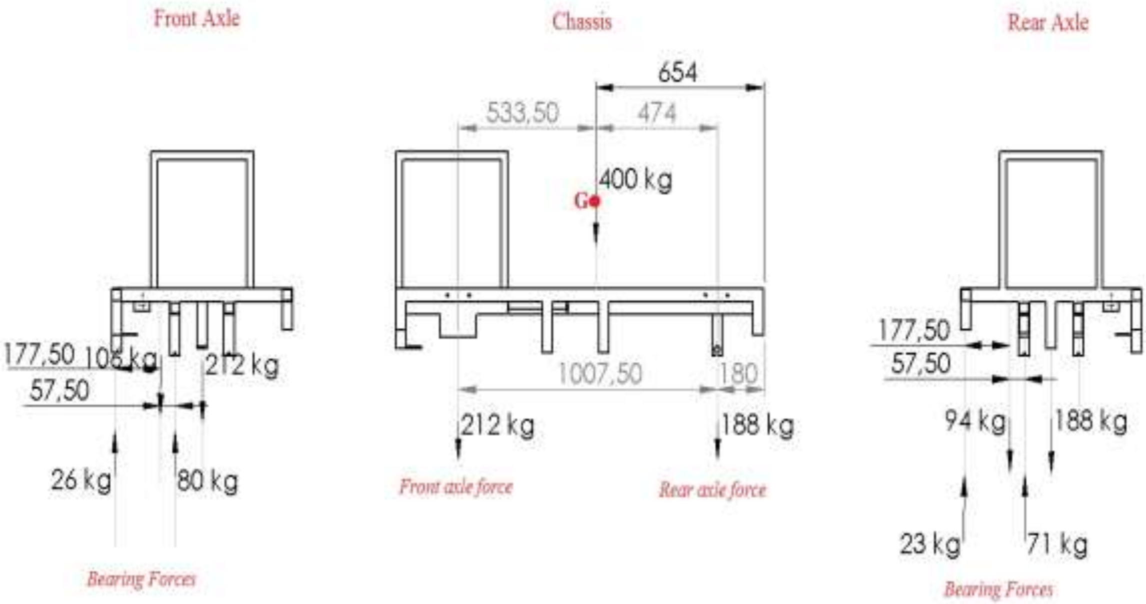


Figure 3.4 Load distribution for housing

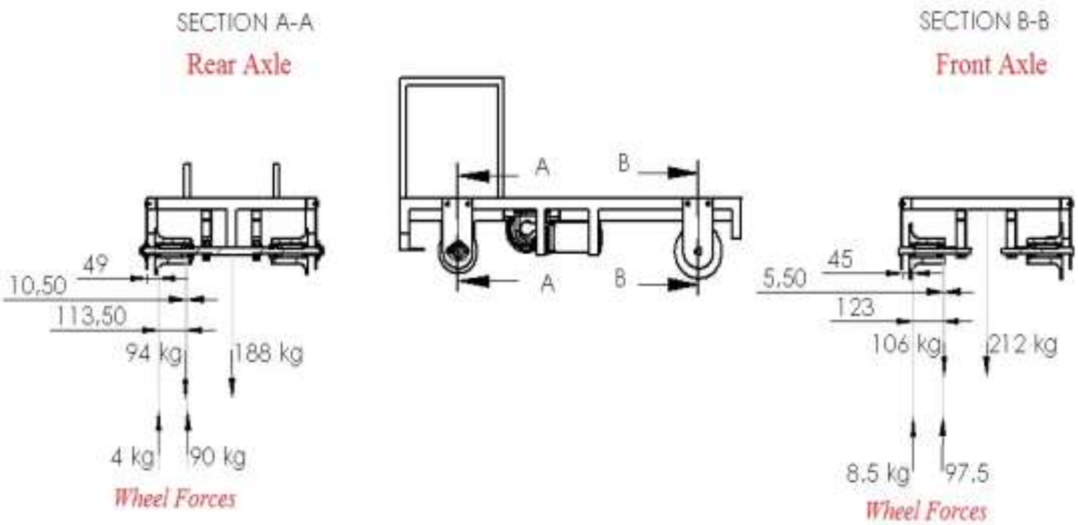


Figure 3.5 Load distribution for wheels

Initial conditions and forces have been taken from Figure 3.4 and 3.5, otherwise SolidWorks modeling has been used for creating applied areas.

3.3.1 CosmosWorks Analysis

Front axle – Axle is fixed from two side and wheel reaction forces have been applied. AISI 1020 material has been applied for simulation. Stress and displacement results are shown in Figure 3.6 and Figure 3.7.

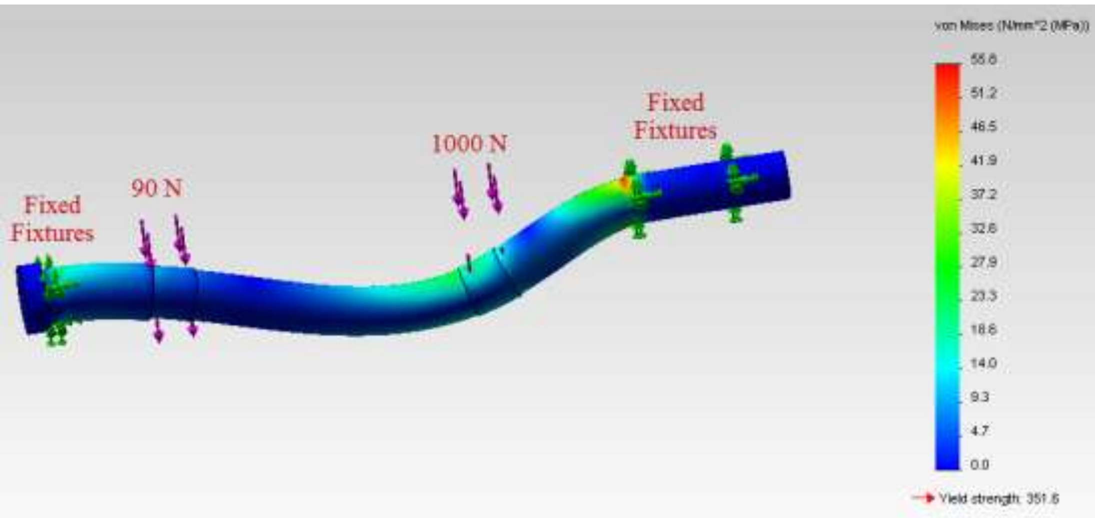


Figure 3.6 Front axle Von-Mises stress results

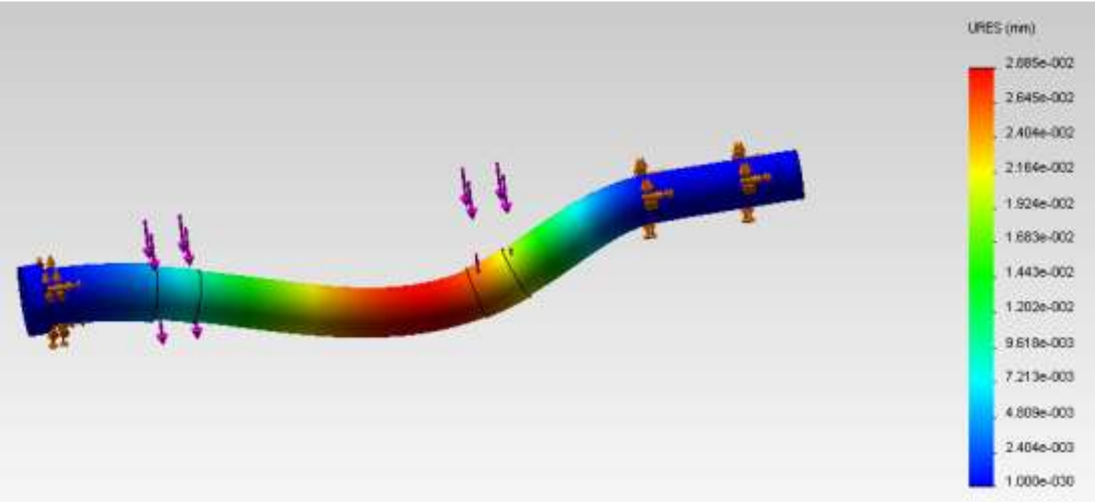


Figure 3.7 Front axle displacement results

Rear axle – Fixed initial conditions and 900 N and 40 N forces have been applied the axle. Fixed areas have been covered with bearing houses. AISI 1020 material have been applied and results are shown in Figure 3.8 and Figure 3.9

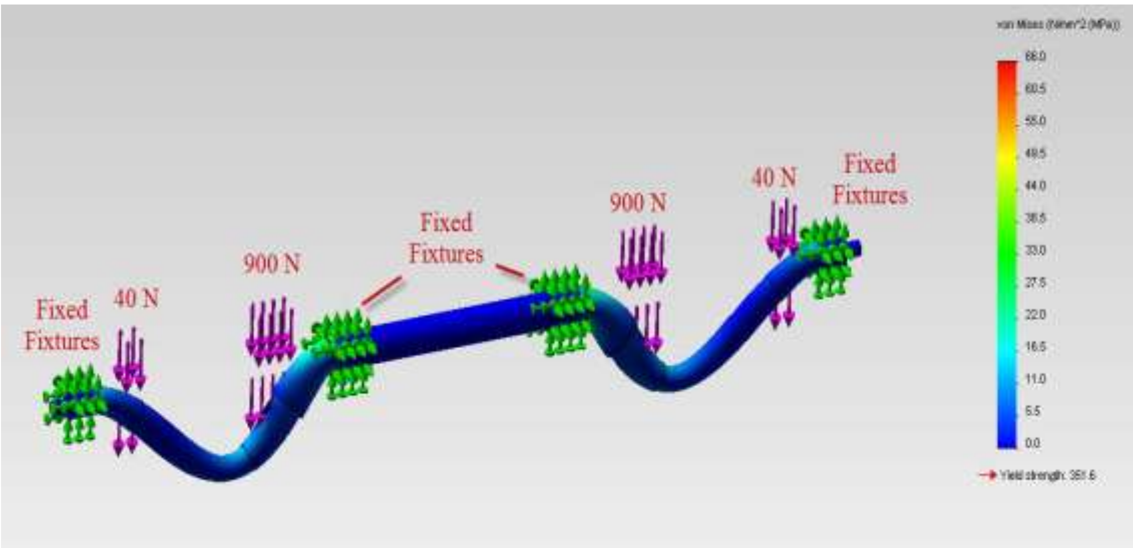


Figure 3.8 Rear axle Von-Mises stress results

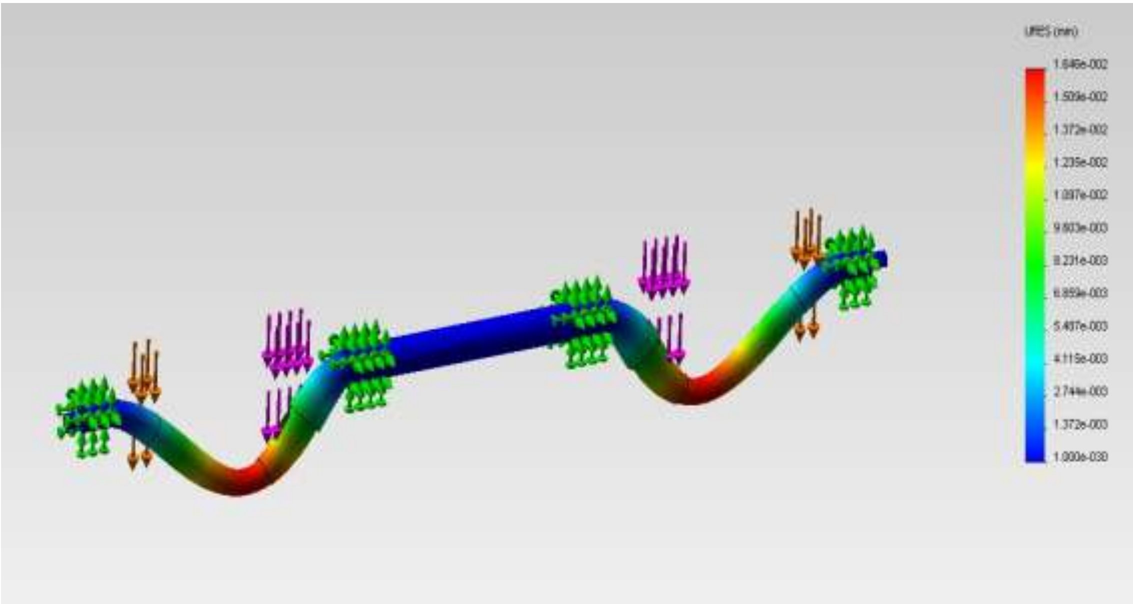


Figure 3.9 Rear axle displacement results

Main chassis – This part is the main carrier of the vehicle which links the other parts. In this simulation, gravity has been applied from the center of mass and 4000 N has been selected by distributed load. Motor side of the chassis has been fixed and roller slider fixtures have been used at the front side of the chassis where free wheels have been located. AISI 1020 material has been applied to the part. This is the most important simulation of the vehicle.

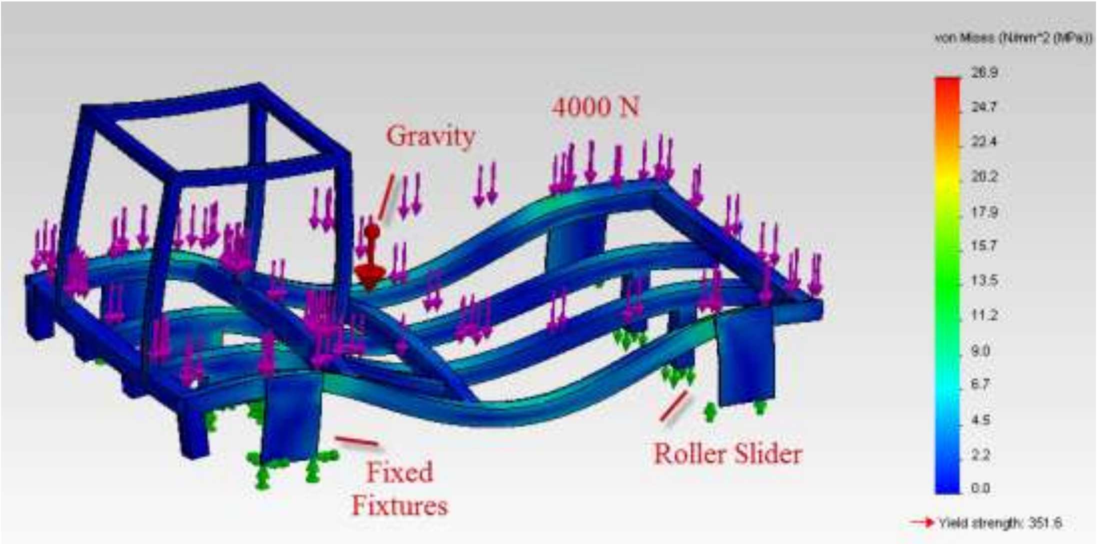


Figure 3.10 Main chassis Von-Mises stress results

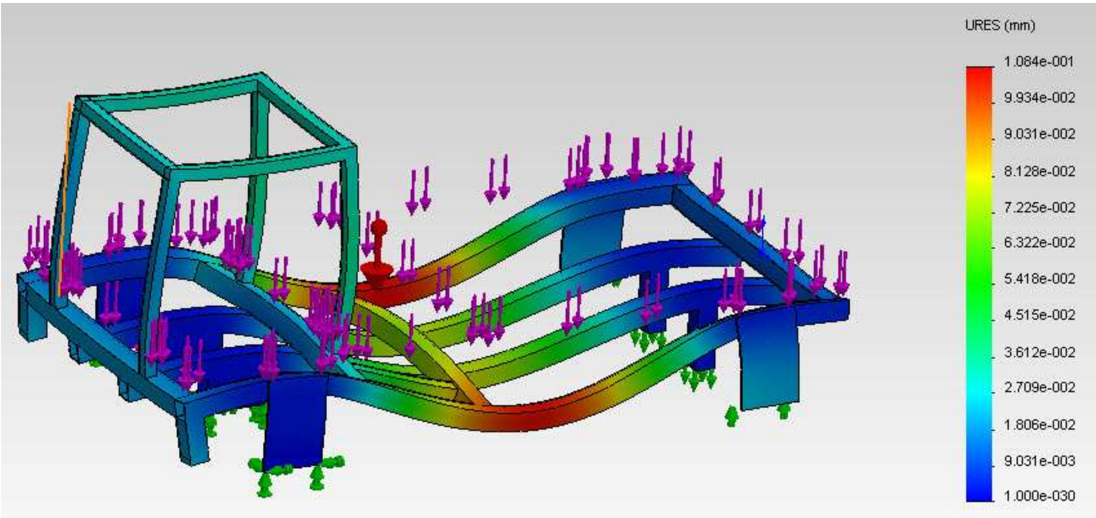


Figure 3.11 Main chassis displacement results

Tank chassis – Pesticide tank has been analyzed in this part. In order to involve tank mass, 200 kg as reduced mass; a special material has been applied to the part and only gravity force has been applied. The part is fixed from bolt hole.

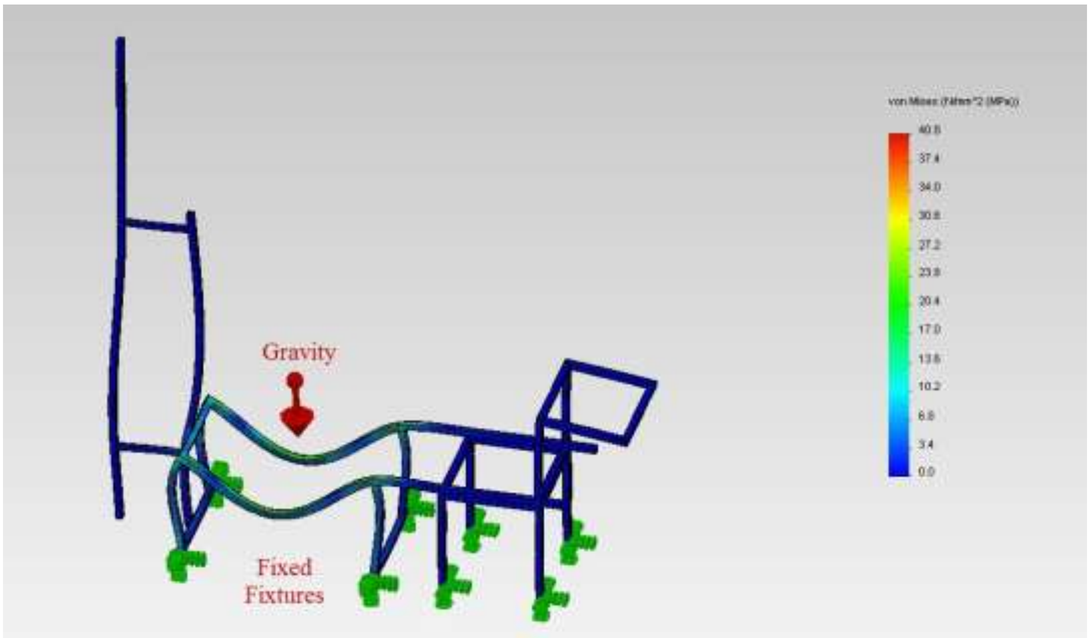


Figure 3.12 Tank chassis Von-Mises stress results

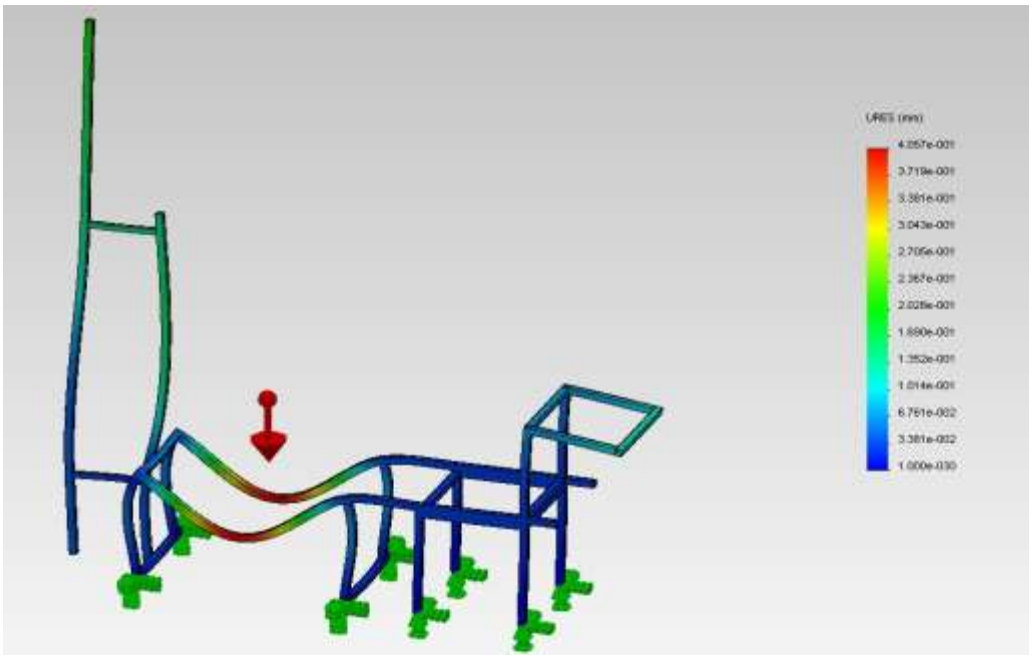


Figure 3.13 Tank chassis displacement results

Caster House - Caster profile is linked the caster house with small pin. While spraying, when vehicle gets out to the hall, caster hits the hall ground. So reaction forces occures at the caster house.

House is fixed from the top face by welding and 2000 N bearing load has been applied for pin force. AISI 1020 material has been selected.

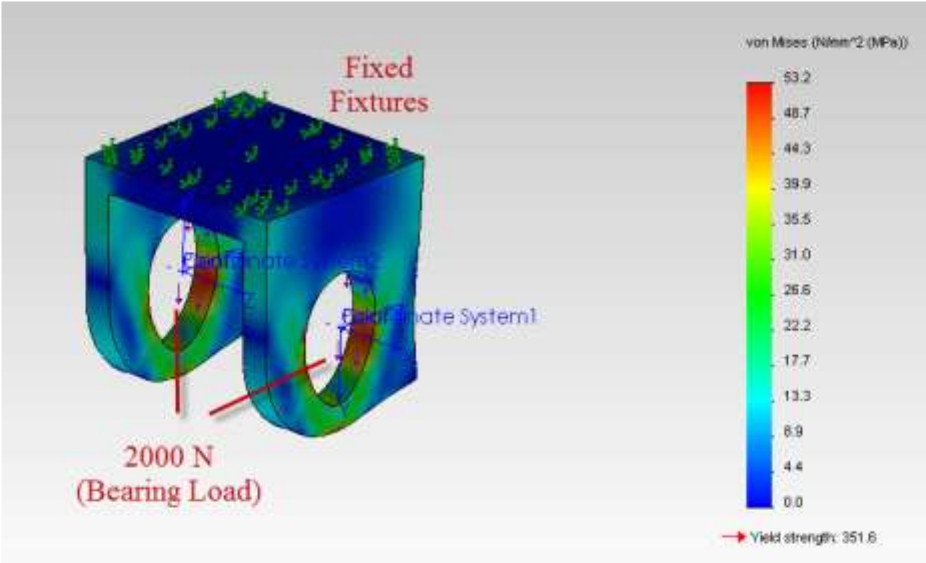


Figure 3.14 Caster house Von-Mises stress results

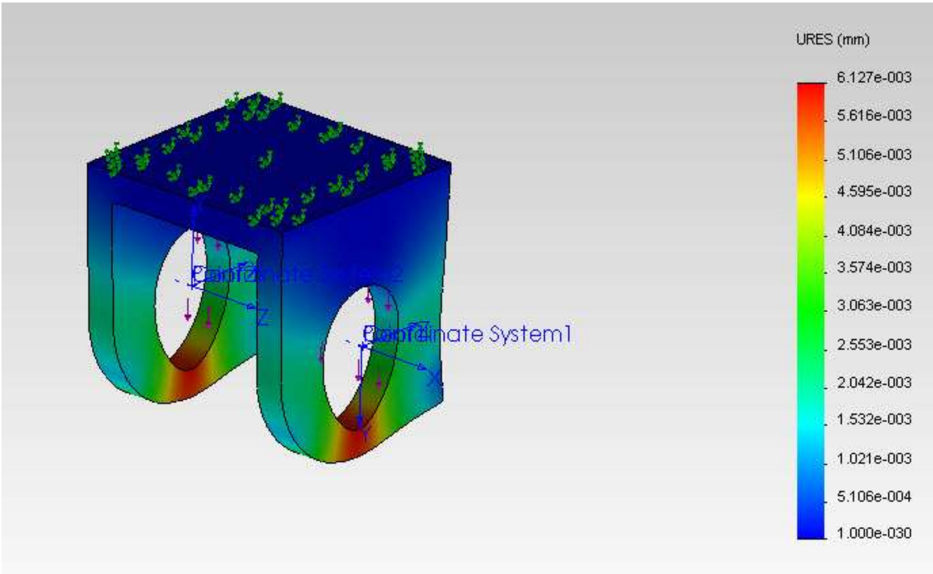


Figure 3.15 Caster house displacement results

Panel Flexible Beam - This part is used to link panel to the chassis flexibly. Flexible beam has been fixed from two holes with bolts and panel mass force has been applied from panel link holes. AISI 1020 material has been applied.

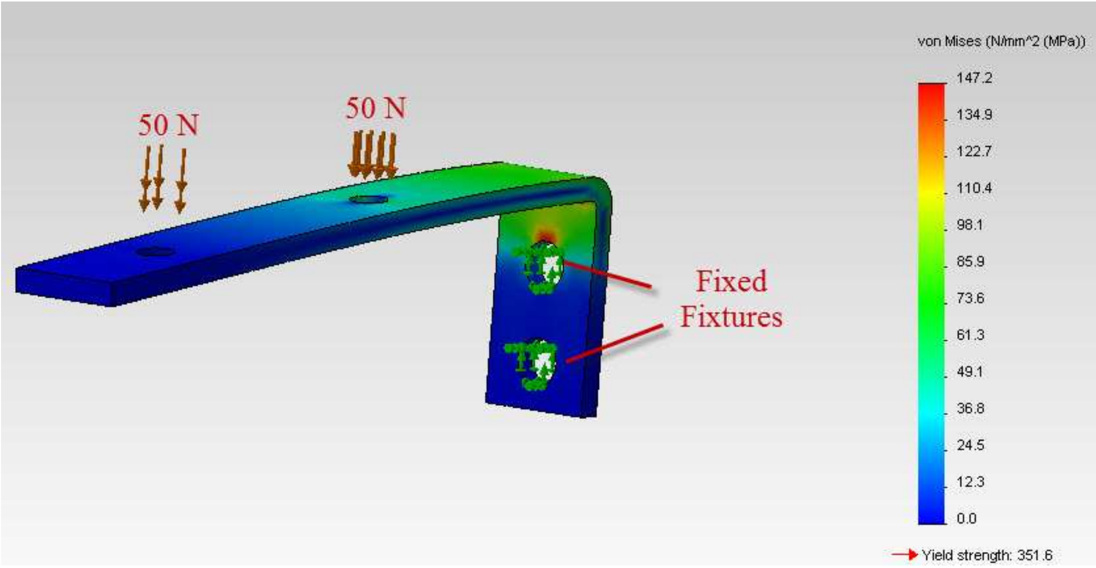


Figure 3.16 Panel flexible beam Von-Mises stress results

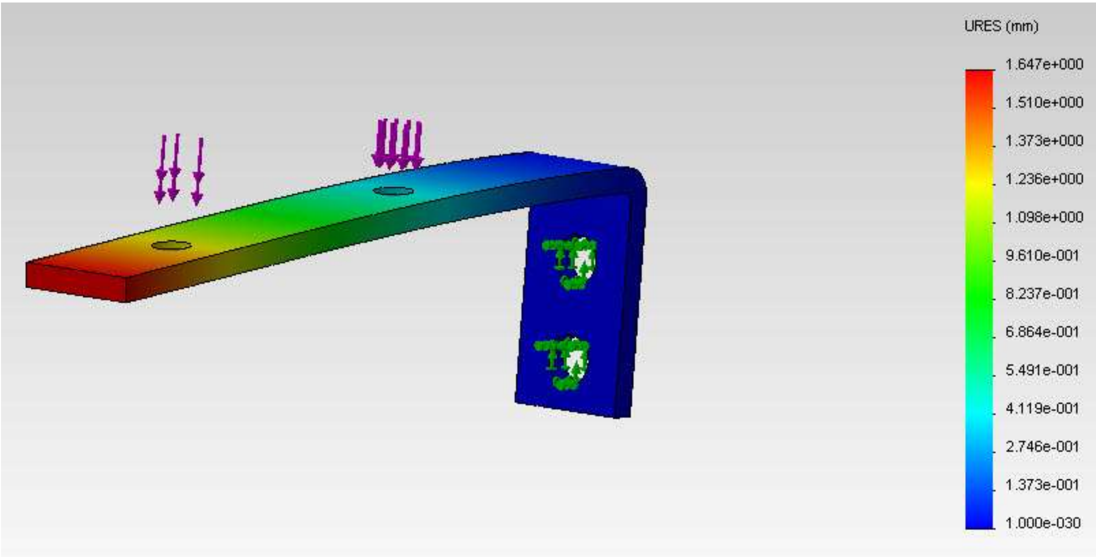


Figure 3.17 Panel flexible beam displacement results

Manual Ladder - When autonomous system is out of order, control panel transforms to the manual drive and ladder lowers for standing on it to drive the vehicle manually. Force has been applied as 1600 N which equals to two men's weight which is 80 kg for each, standing on the ladder. And assembly has been fixed from the hinges.

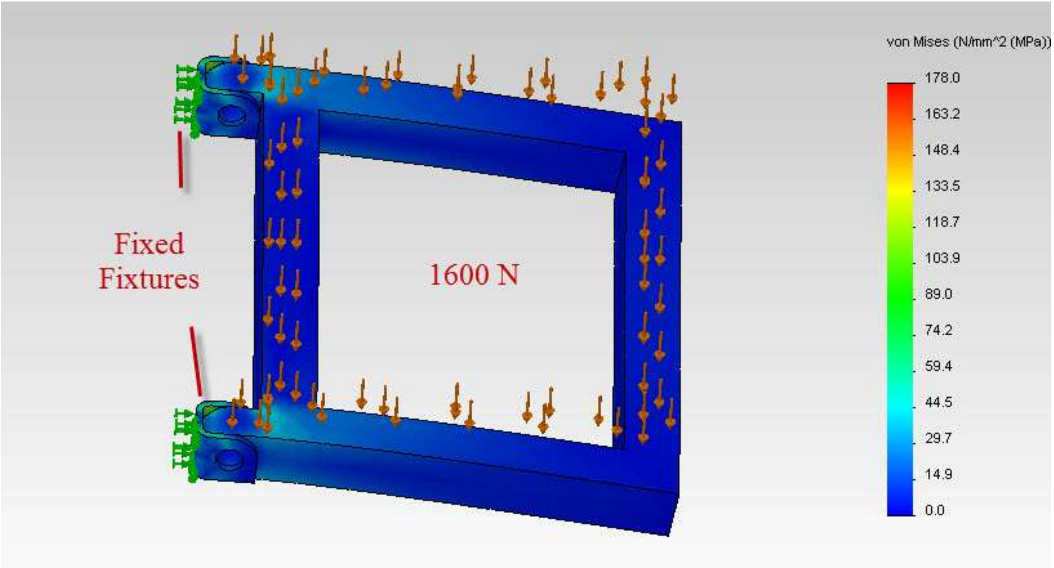


Figure 3.18 Manual ladder Von-Mises stress results

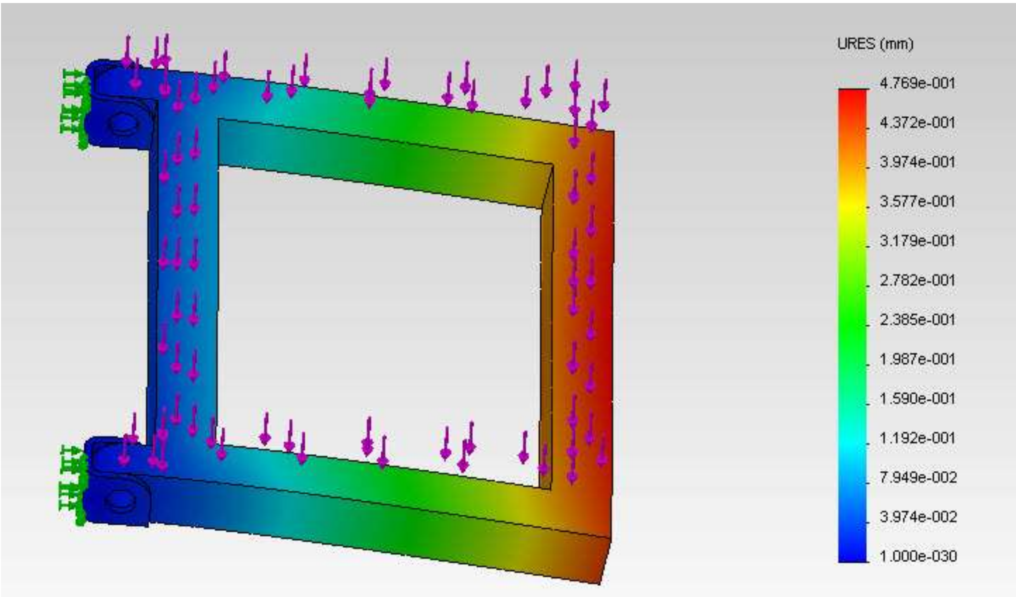


Figure 3.19 Manual ladder displacement results

Whole Vehicle Analysis – Only gravity force has been applied whole system and motor side of the chassis has been is fixed and roller slider fixtures has been used at the front side of the chassis where free wheels.

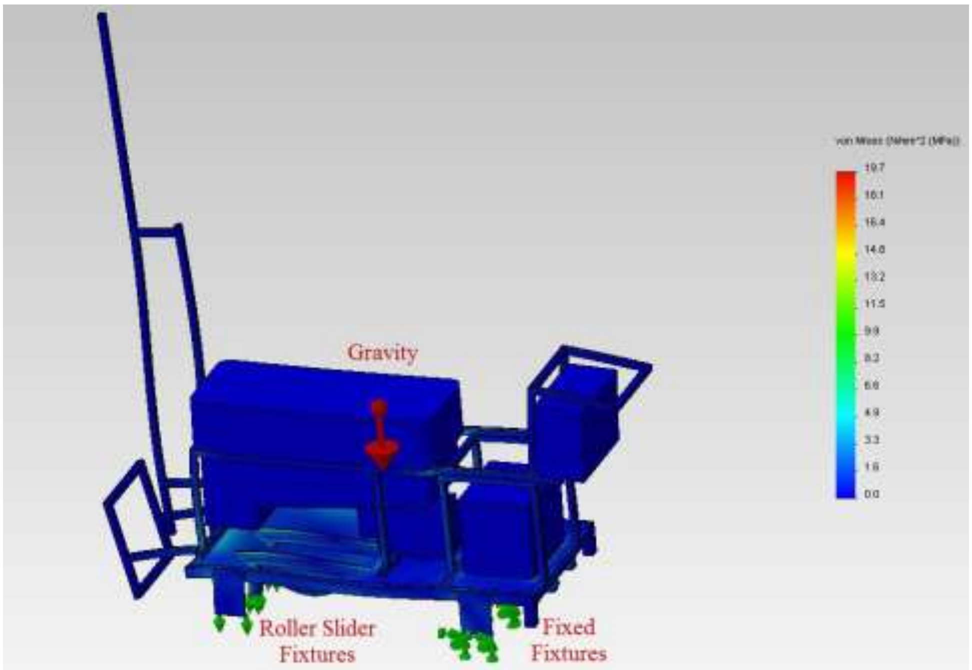


Figure 3.20 Whole vehicle Von-Mises stress results

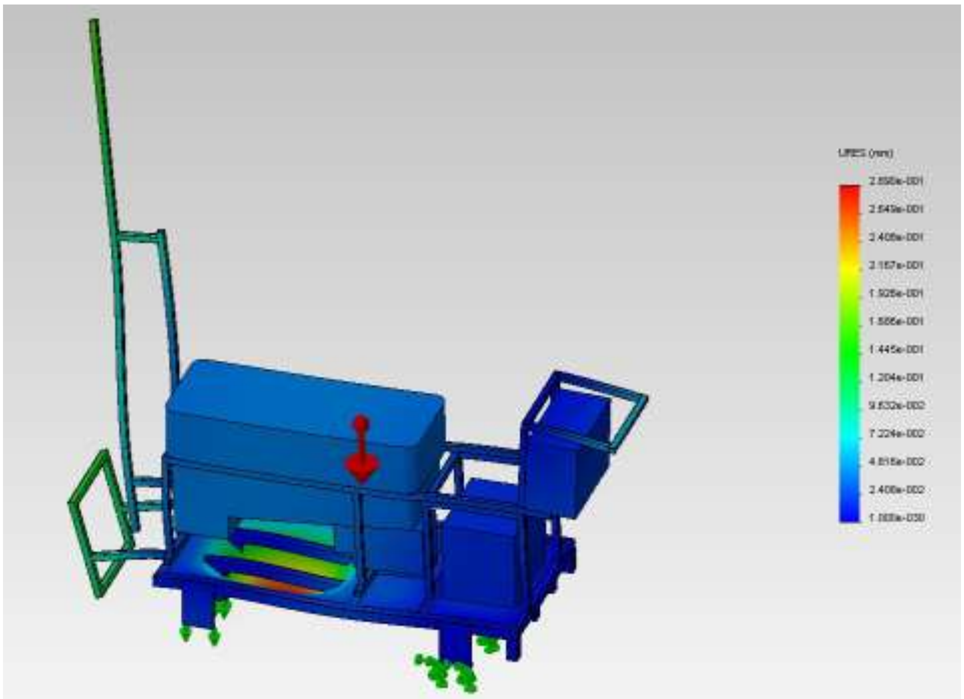


Figure 3.21 Whole vehicle displacement results

3.3.2 ANSYS Analysis

Structure has been fixed from the axle houses. Rear house has been fixed to all DOFs. Only motion which is along the z direction is free for front house, other DOFs have been fixed. Reduced mass and material properties have been applied to the system. Analyze has been done for deciding choosing a 150 or 200 liter tank. In the result images, SMX is the maximum strain and *SMN* is minimum strain. Also maximum displacement is represented by *SMX*. For 150 liter tank strain values are given in Figure 3.22 and for 200 liter is given in Figure 3.23.

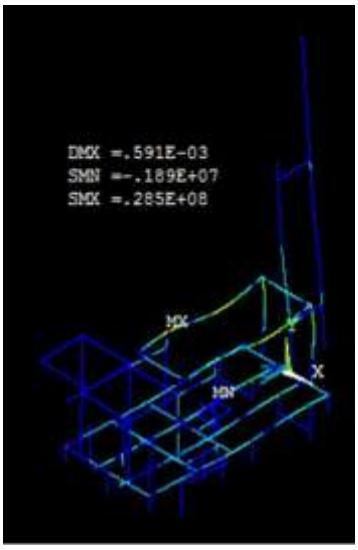


Figure 3.22 Stress results for 150 L tank

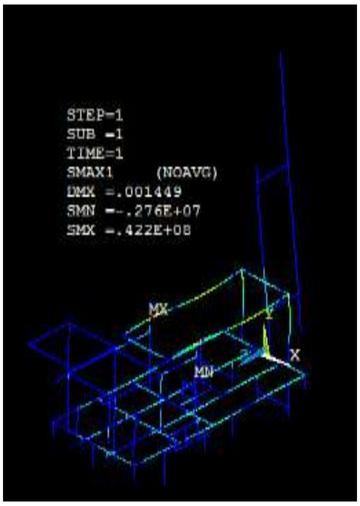


Figure 3.23 Stress results for 200 L tank

3.4 Modal Analysis

Dynamic properties of the structures under the vibrational excitation is measured by modal analysis. Analysis is done when excited by inputs as shaker etc.

3.4.1 CosmosWorks Analysis

For natural frequency analysis, force has been not applied. Only initial conditions has been applied. Initial conditions are same as static analysis fixtures. First three frequencies have been calculated.

According to the frequency analysis; new beams, structures or brackets has been added as frequencies must be over the working frequency. Coordinate system has been selected as shown in Figure 3.24.

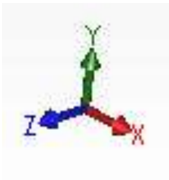


Figure 3.24 Coordinate system

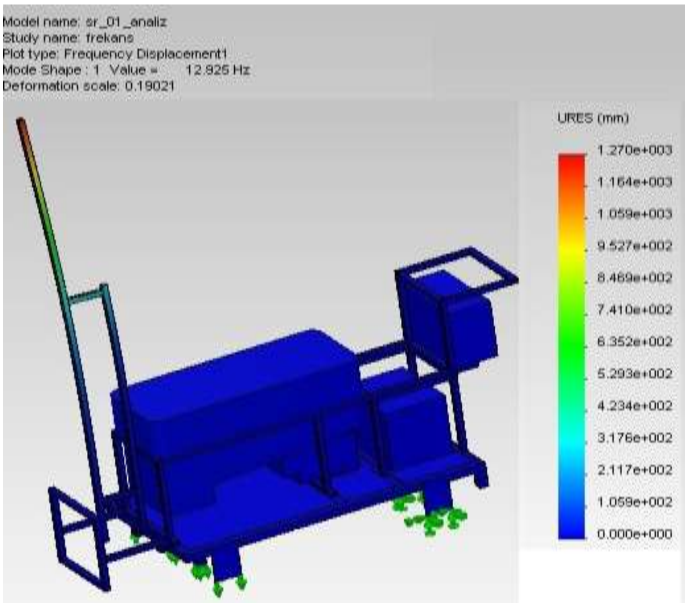


Figure 3.25 Natural frequency mode shape 1

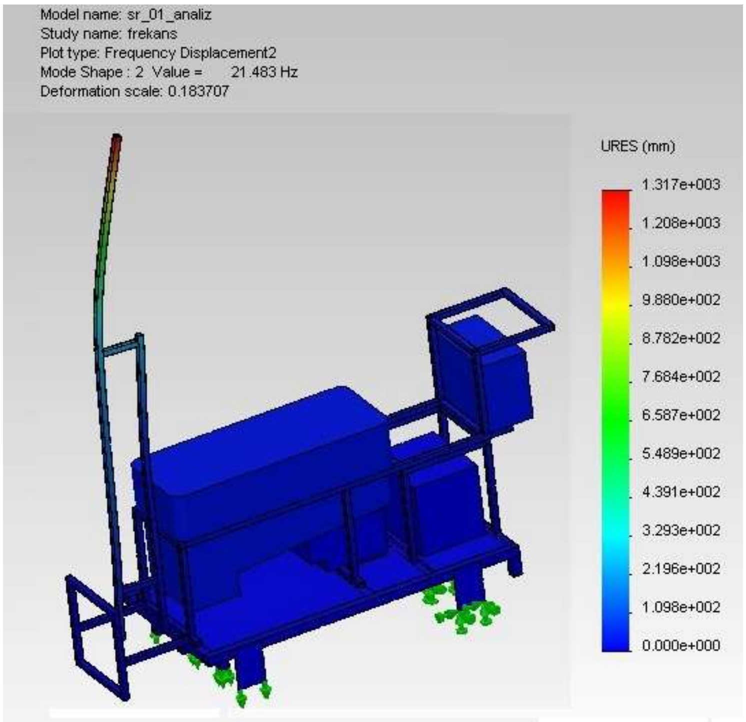


Figure 3.26 Natural frequency mode shape 2

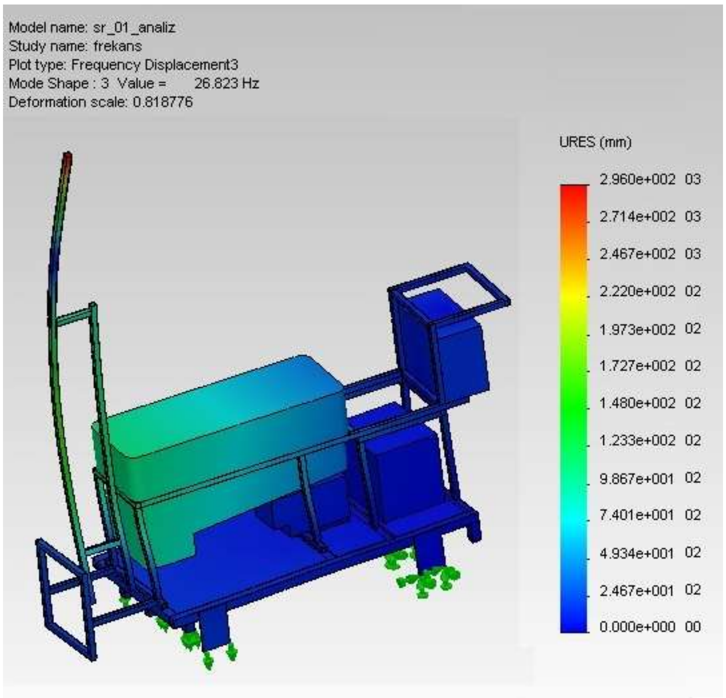


Figure 3.27 Natural frequency mode shape 3

3.4.2 ANSYS Analysis

In Figure 3.28 first structure is SolidWorks beam system, second is assigned mass system in SolidWorks and third is ANSYS beam system.

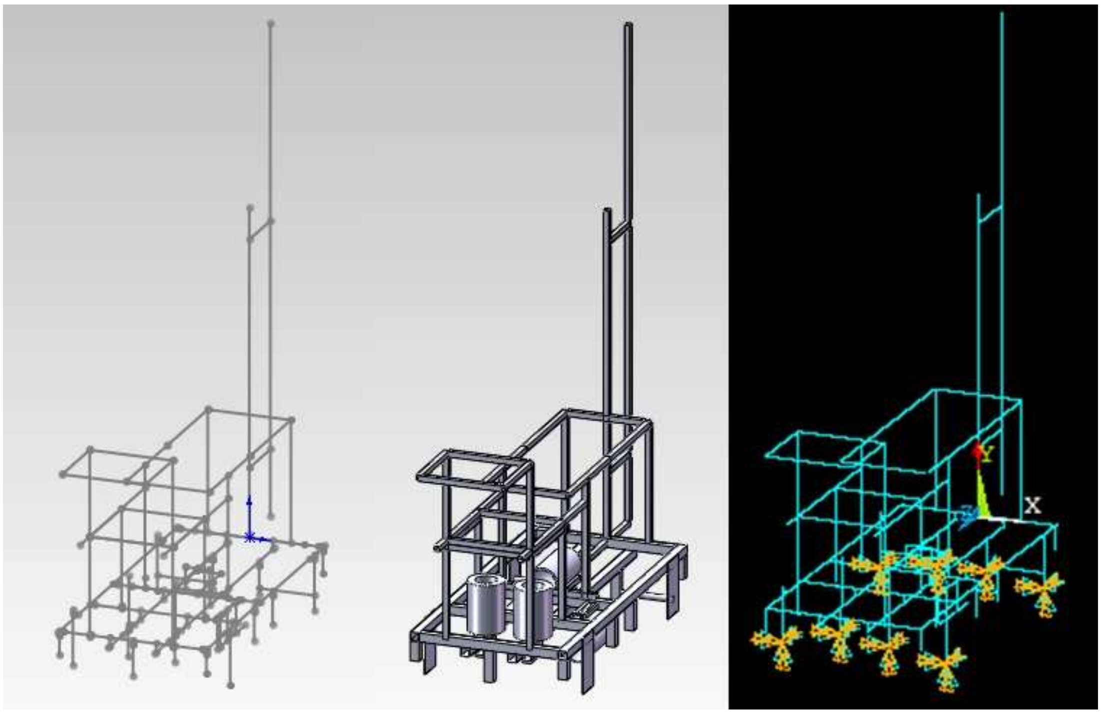


Figure 3.28 Solidworks and ANSYS co-work with Visual Basic API

Modal solution has been applied for first three frequencies. *DMX* is the maximum displacement and *FREQ* is frequency. Also mode shape is represented by *SUB.*

First simulation has been done with 150 liter tank and simulations have been repeated with 200 liter tank and results are given in Figure 3.29 and Figure 3.30.

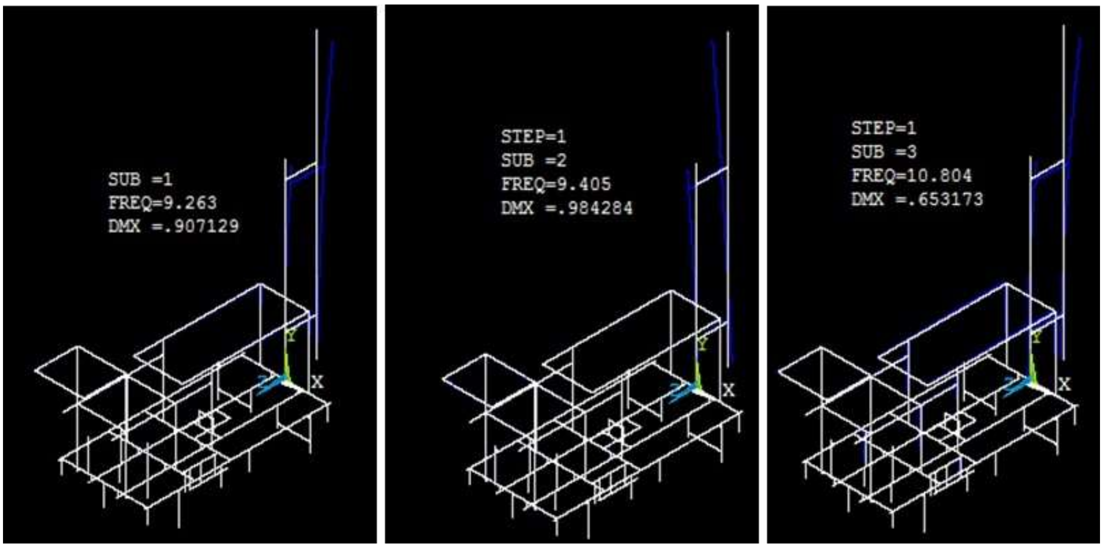


Figure 3.29 Natural frequency results for 150 L tank

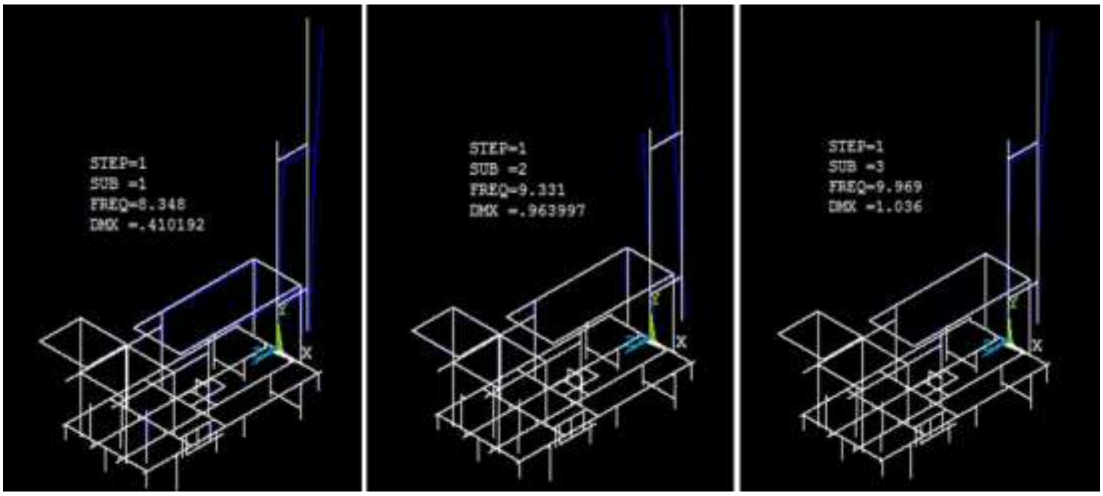


Figure 3.30 Natural frequency results for 200 L tank

3.6 Motion Analysis

Motion analysis is the simple case to detect motion, find points in the image where something is wrong.

In this study; a velocity time history data has been entered to the program as an input. Furthermore; power consumption, motor torque values have been calculated. Also reaction forces have been checked.

Time history of the velocity and acceleration profile which is required for forward motion is given in Figure 3.31, and for spraying motion is given in Figure 3.32.

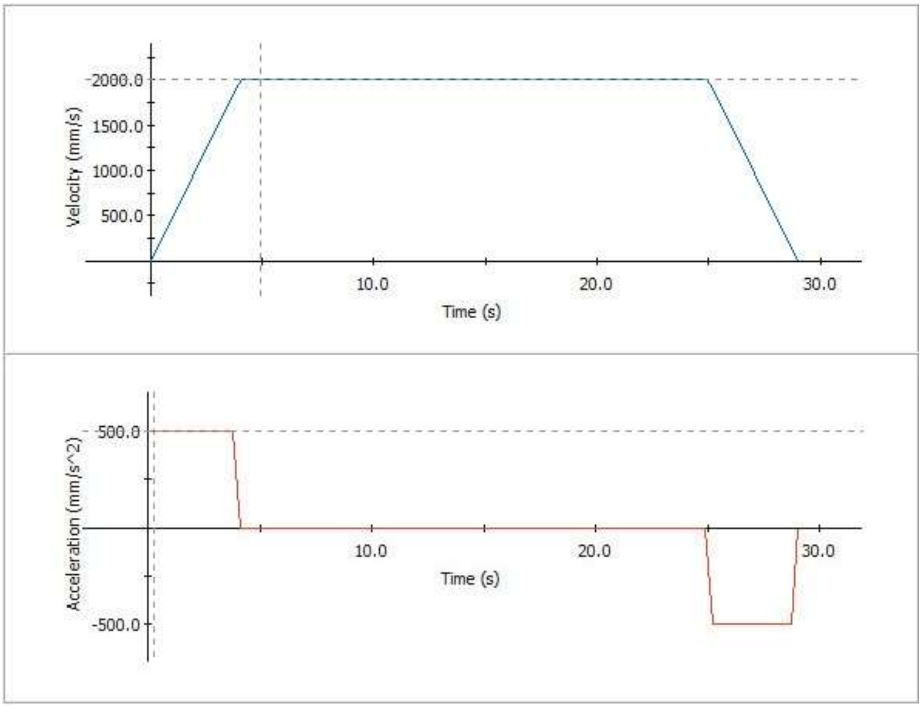


Figure 3.31 Forward motion velocity and acceleration profile

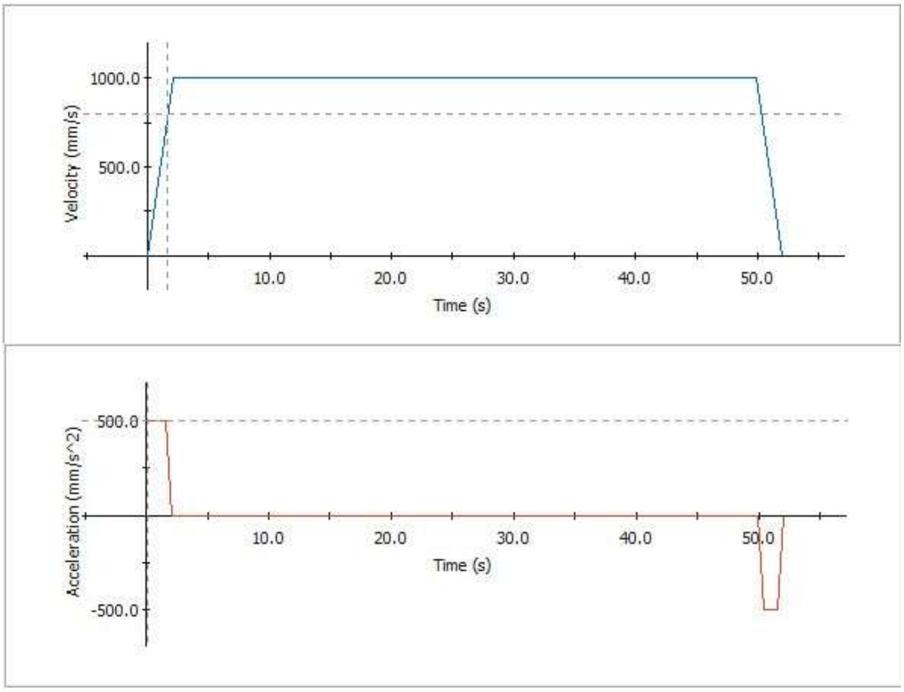


Figure 3.32 Spraying motion velocity and acceleration profile

First wheels and heating pipes where wheels have been driven on, are contact with each other and time history of the radial velocity of the wheel has been input as shown in Figure 3.33, rolling resistance force has been applied in Figure 3.34 and calculating graphs are as given in Figure 3.35.

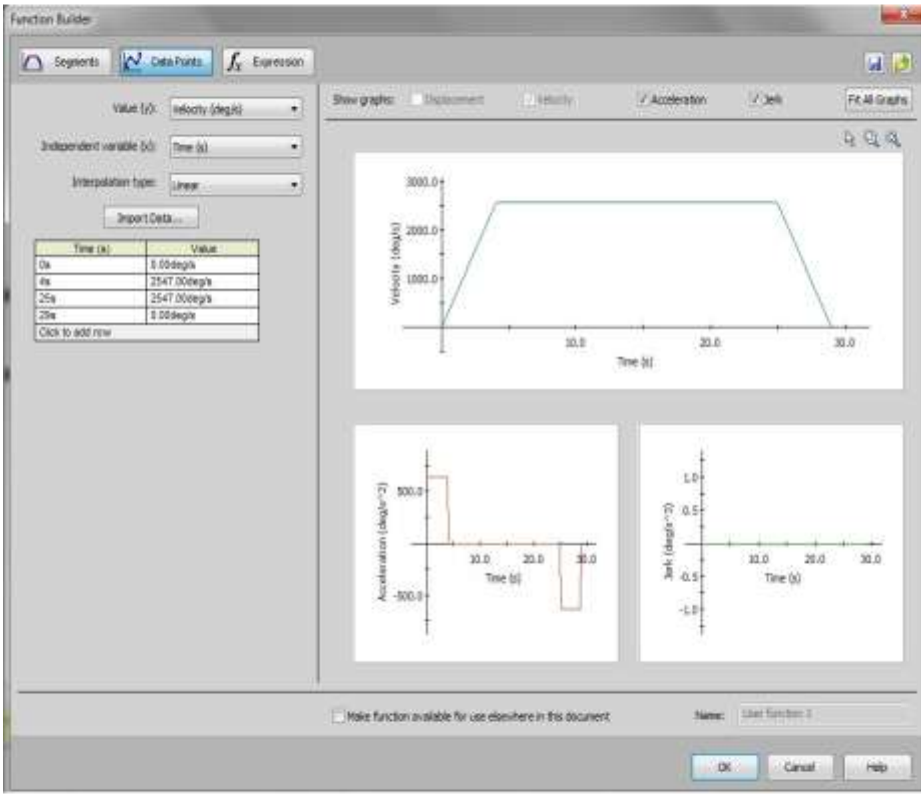


Figure 3.33 Time history of the velocity and acceleration profile

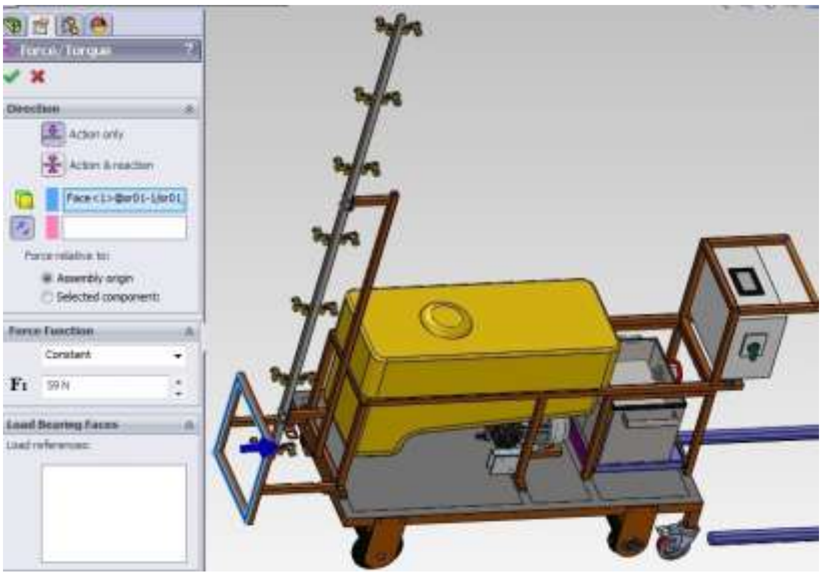


Figure 3.34 Reaction force

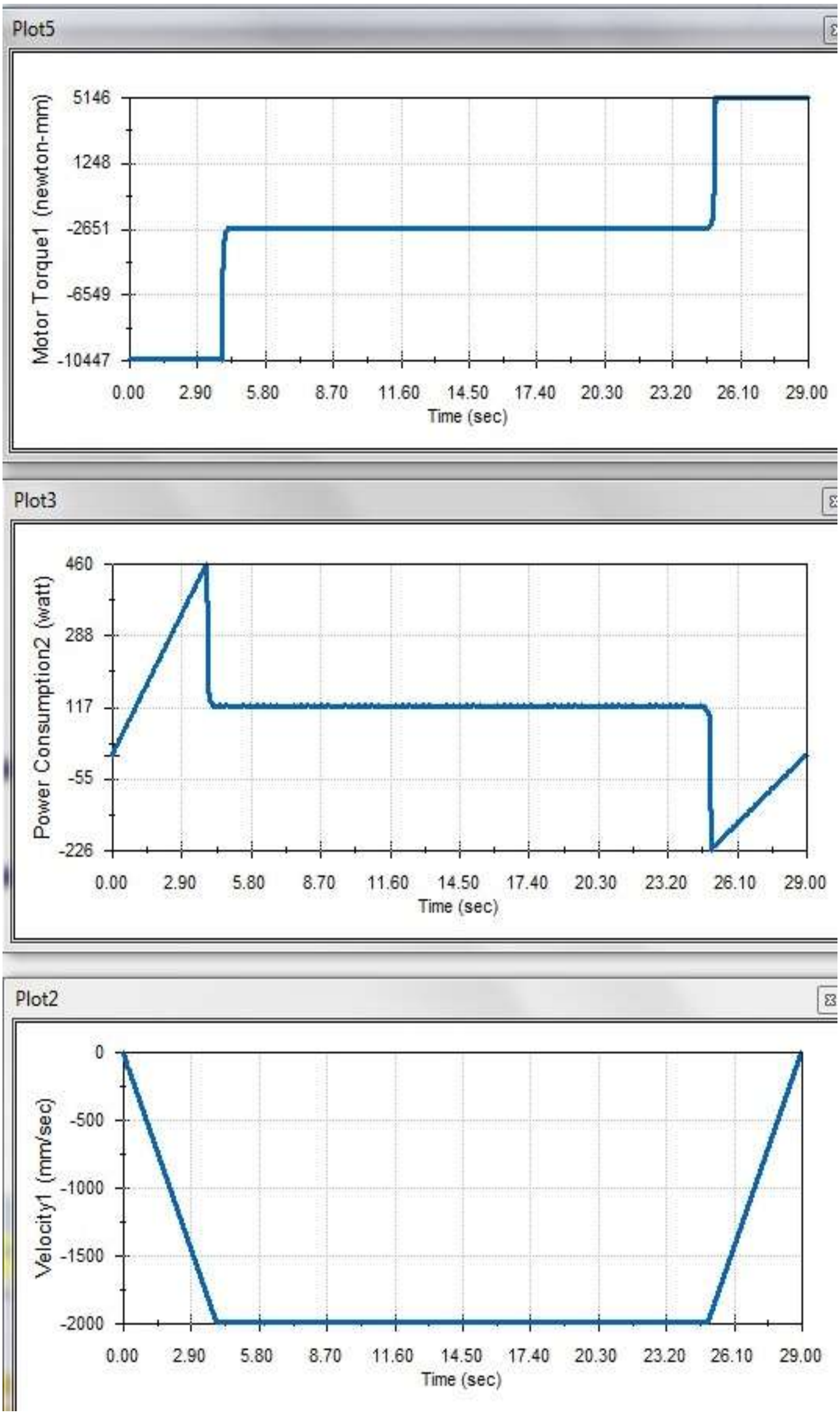


Figure 3.35 Result of motion analysis

CHAPTER FOUR
CONTROL SYSTEMS

The control system is the most significant section of autonomous vehicles. This system varies according to the operational environment conditions, vehicle specifications and usage area.

In this study; a control panel has been developed for the automated movement of the vehicle. The control panel consists of a DC motor driver, PLC (Programmable Logic Controller), contact, relay and fuses. A distance sensor for the localization of the vehicle has been used and a mechanical switch has been integrated to stop the vehicle at the start and end points of the row. Control software has been established with the assistance of the PLC for the automated movement and pesticide spraying.

Vehicle's 30 x 40 x20 (mm) control panel layout is seen as Figure 4.1.

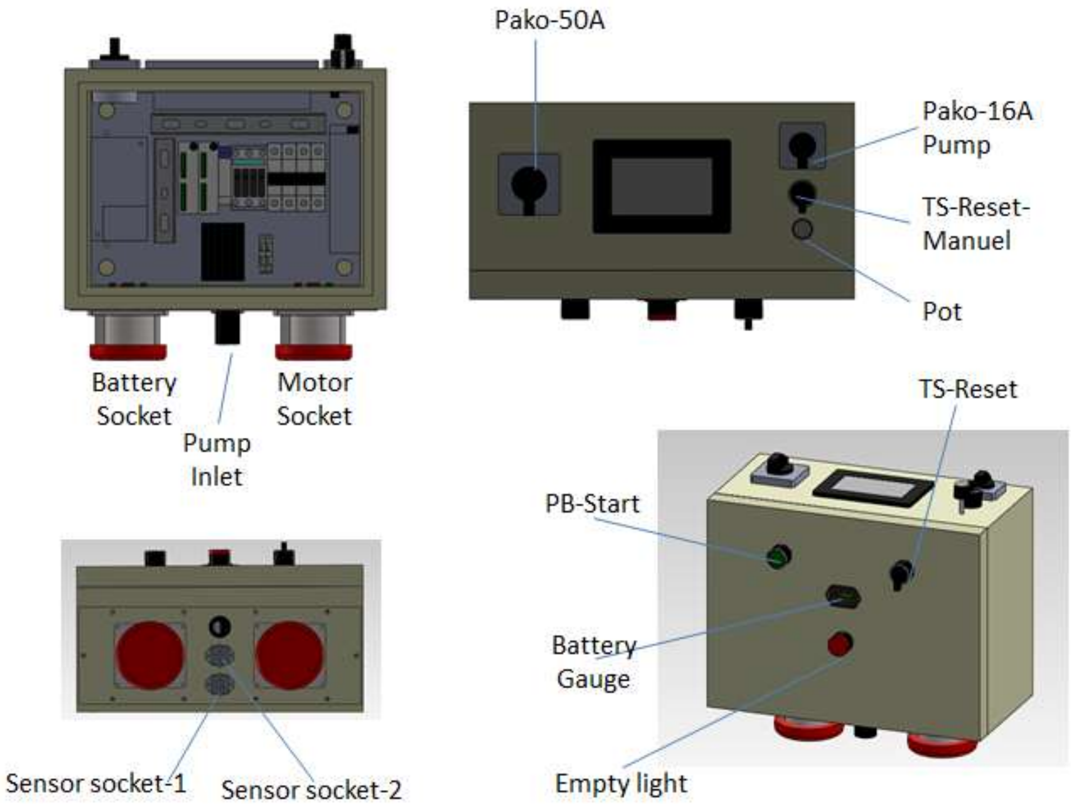


Figure 4.1 Control panel

The panel is supplied with 24 V by two serial connected 12 V batteries. The voltage input to the panel is conducted with a DC to DC voltage regulator to protect the components from the voltage fluctuations. Separate fuses exist for the driver, PLC and pump.

50 A Pako switch, which is located on top of the panel, is to cut off the main current. 16 A Pako switch is used to start up the pump manually; a toggle switch has a manual reset function and the potentiometer is used to drive the motor manually.

The green push button in front of the panel starts the vehicle automation and the toggle switch acts as an automatic system reset. Moreover, a warning red light which indicates that the tank is empty and a battery indicator exist in the panel.

The automation of the vehicle can be described as below:

PLC transmits a signal to the motor driver when the push button is pressed and then the vehicle starts its movement with the velocity that is entered to the display. The push button does not operate if the tank is empty and the red warning light is on. When the vehicle moves forward and distance sensor detects the distance, which has been entered to the distance sensor, the second assigned velocity, which is slower than the first predefined velocity; is assigned by the PLC through the motor driver. The motor stops and PLC resets itself when the limit switch hits the stopper which has been welded to the pipe or if the stopper does not exist; when the stand-by time is up. The forward movement is completed with these steps.

The comeback movement, which means the spraying process, is started with a signal transmission from the PLC to the pump relay. After that, the driver sets the motor in the opposite direction and returns the vehicle with the comeback velocity to the end of the row. When the vehicle exits the row, limit switch hits the pipe and sends a signal so that the PLC cuts down the 24 V which flows to the motor driver and allows the motor to break and stop the vehicle. The pump is shutdown when the switch is triggered and the time which has been entered to the display ends and through this last step, one cycle of the automation is completed. Detailed PLC connection is given in Figure 4.2.

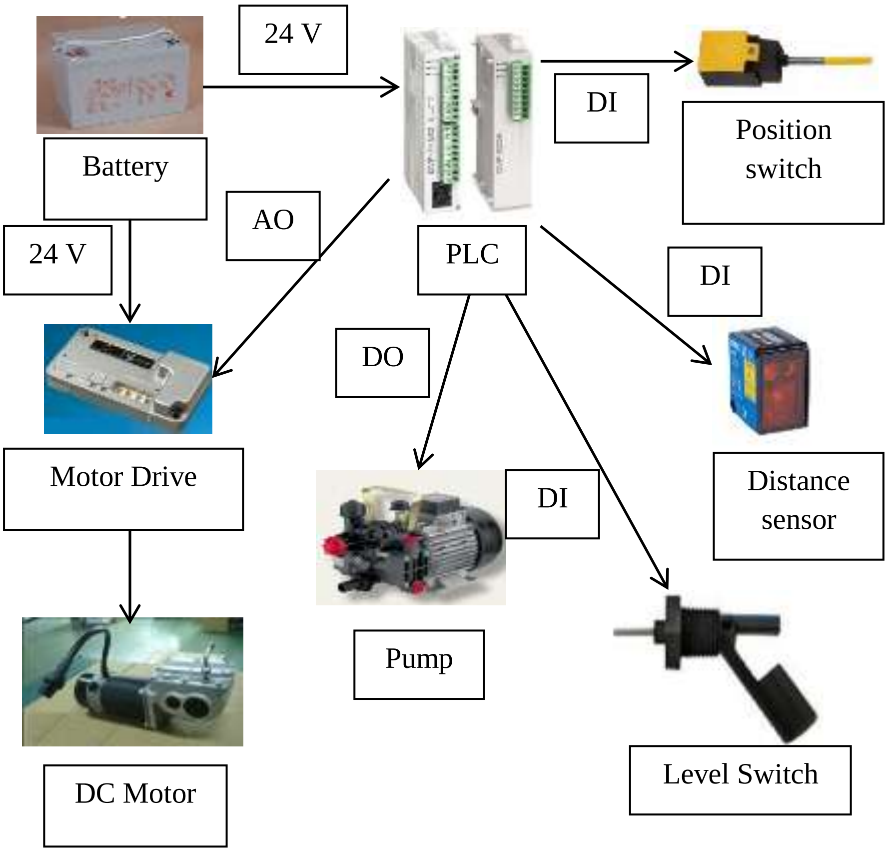


Figure 4.2 PLC connection

PLC and motor drive are fed by battery. When PLC analog output (AO) sends signal to motor drive between 0 and 5 V, motor start to turn forward (0 - 2.25 V) or backward (2.25 – 5 V). If AO send 2.25 V motor stops. Pump is linked to digital output (DO). Cause pump works as a on-off system. If 24 V comes, it works; 0 V comes it stops. Sensors are linked to digital inputs (DI).

This project has been prosecuted with a commercial company. So product names of the sensors and detailed control chart of the vehicle couldn't be given in this study due to the copyright law.

4.1 Motor Drive

Motor drivers that communicate with the PLC are used for the automated drive of the motor. There is software for these drivers to define the velocity and acceleration values. Motor driver circuit is one of the major application areas in power electronics. The aim is to control the velocity, position or moment.

The process is the most important factor for defining the motor driver design. For instance, a servo driver is required in robotic applications, however motor drivers, those regulate the velocity, is needed in facility air conditioning applications. Furthermore, sensitivity and response time are not significant factors in many applications. There is an outer cycle that controls the process aside from the motor driving system, as it can be seen from Figure. Therefore, the sensitivity and response time of the motor driver system is not fundamental.

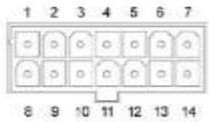
The driver controller is suitable for entire range of mobility scooters and similar electric vehicles The electronics of the driver are sealed against water ingress IPX5, and when the optional connector sealing system is fitted the cable connections are protected IPX4. It is available in 45 A, 70 A, 90 A, 120 A, 140 A and 180 A power versions. Diagnostics logs, brake light operation, free wheel speed limit function, extensive audible and visual diagnostic alarm capabilities features are included. A connection diagram of a motor drive is given at Appendix, in Figure 7.6.

General properties of the driver are given below:

- Advanced drive algorithm
- Choice of power ratings
- Freewheel speed limit
- Electronics sealed to IPX5
- Connection ports sealed to IPX4 with optimal cover
- Extremely compact with very small footprint
- Industry standard connectors across the entire range

- Programmable diagnostic output
- System log – provides a record of all trip conditions
- Hours run timer function
- SP1 or PC programming
- TUV approved
- Designed to ISO7176/14 and EN12184

An example of driver connection is given Figure 4.2.



Pin Number	Description
1	Throttle Wiper
2	Throttle High Reference
3	Audible Alarm
4	Slow/Fast Switch
5	On/Off Switch
6	Inhibit 2
7	24V B+ (S180 fused 3.75A)
8	Throttle Low Reference
9	Speed Limiting Potentiometer
10	Status Indicator
11	Aux Output
12	Reverse Switch
13	0V
14	Inhibit 3

Figure 4.3 Driver pin table

The driver regulates the motor velocity, direction and the timing by communicating with the PLC.

An interface of the driver software, velocity and acceleration values for the vehicle are shown in Figure 4.4.

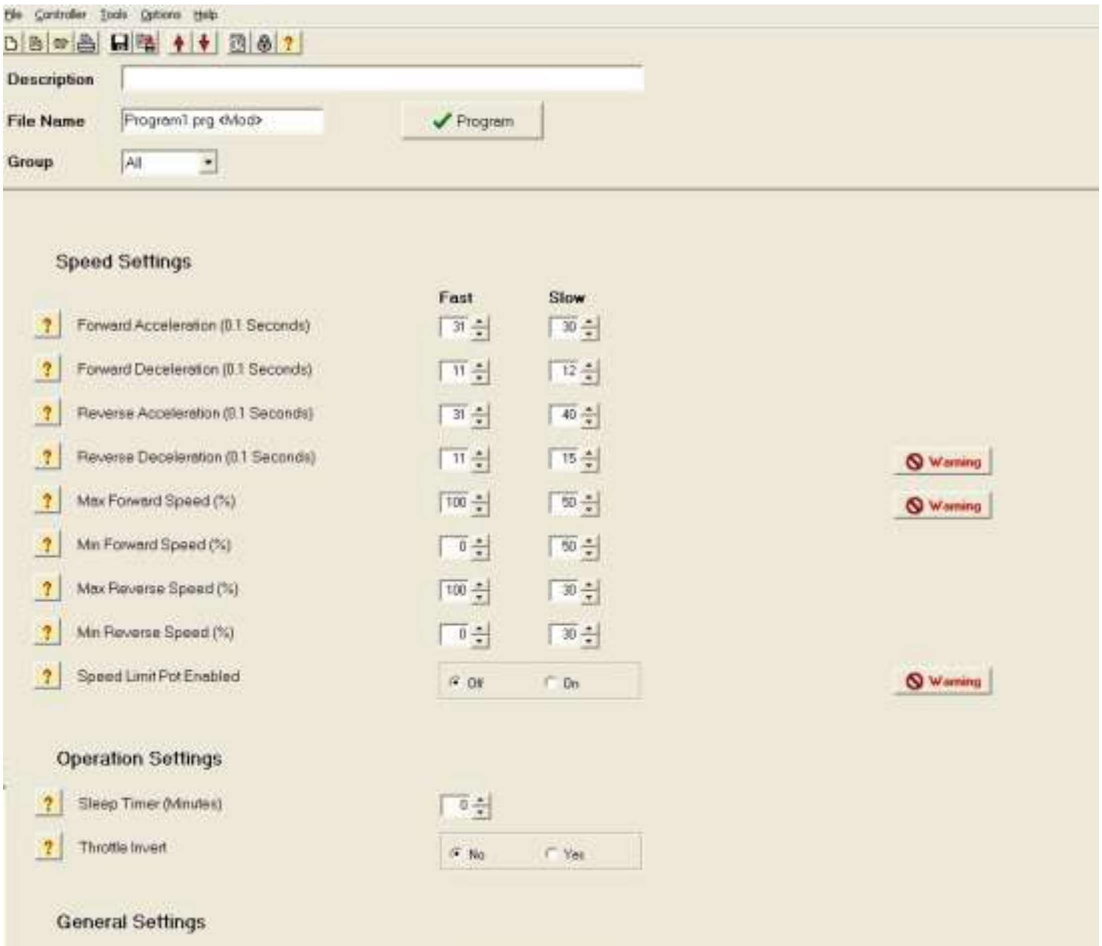


Figure 4.4 Driver software

4.2 Programmable Logic Controller (PLC)

The automation and general purposed control studies in every section of the industrial applications have led to the PLC approach, which is a subgroup of a technology that allows the users to have a wide range of solutions.

PLC is a microprocessor system that processes the data received from the sensors and transmits them to the actuators.

PLC controls numerous machines and systems through its input and output connections. In this way, it is an integrated system that consists of compartments. These compartments contain, timer, counter, data processor, comparator, arranger, memory, CPU, programmer sections, inputs and outputs, which assigns signals to the output by using the input data and supported with a programming capability through a 8-16 bit data transfer. There are also many internal (assisting-storing) relays, timer relays inside the device.

Steps to set up a control system with a PLC:

- Specifying the control problem
- Defining the required program and functions for the solution.
- Operability check of the program with time diagram and wave types.
- Integration of the program to the diagram(LADDER STL, SCL, FBD)
- Coding the program

There are 5 developing main application areas of PLC in food processing and its services. A common setup is conducted with a solution to the control system problem and may contain one or more of these. These fields are as below:

1. **Sequence Control:** The most commonly used application of the PLC and is the most similar one to the systems with relays. It is used in independent machines or machine lines, conveyor and packaging machines, modern elevator control systems.

2. **Motion Control:** It is the joining of linear and circular motion control systems in the PLC and it can be used in servo step or hydraulic drives which can be a system controller with one or more axis. PLC motion control applications consist of a boundless variation of machines.(ex: metal cutting, forming, assembly machines). Cartesian robots, film, rubber and plain cloth textile systems and network related processes can be given as an example.

3. **Process Supervision:** This application is related with the supervision ability of the PLC that can check a couple of physical parameters (temperature, pressure, flow, velocity, weight etc.).This requires an analog I/O to build a closed circle control loop. PLC can handle the tasks of the single loop controllers on its own with the usage of PID software. Another option is to join the controllers by using the PLC and combining the best features of both. Common examples for this approach are plastic injection machines, reheating ovens and other batch-control applications.

4. **Data management:** Data collection, analysis and processing with PLC have been developed in recent years. The system can be used as data collector of the machines or process that it controls due to the advanced training sets and the improved memory capacity in modern PLCs. Later on, this data is compared with the reference data in the controller memory or can be transmitted to another device for inspection and report. This application is often used in massive material processing systems, paper, essential metals and food processing systems.

There is software interface and a sample from the program at Figure 4.5. Timers and doors symbolize all processes that has been done.

In this automation system, it checks the signals coming from PLC, distance sensor and limit sensors and according to these signals it sends signals to the motor driver.

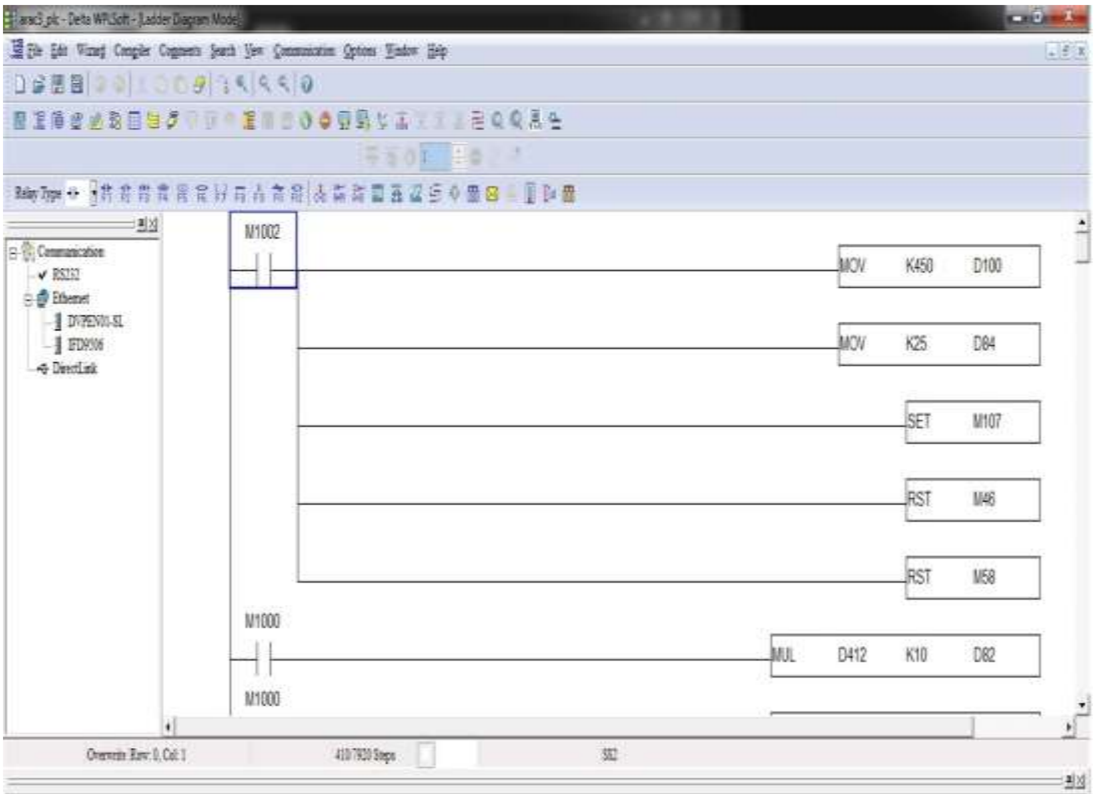


Figure 4.5 PLC software

4.3 Screen

Additional screen is added to the control system compatible with PLC to change speed and time values of the vehicle. On this DOP series, touchscreen wanted screen image is created and related with windows and PLC inputs. So screen images show the speed of vehicle and stop time can be controlled.

“Forward speed 1” represents maximum forward speed, “Forward speed 2” represents the slow speed after distance sensor sees and “Backward speed” represents the pesticide speed. “Front sensor(s)” represents if the front sensor does not detect, stop time of vehicle after distance sensor detects, “pump operate(s)” represents after vehicle goes out of the line and motor stops, how much time the pump operates. “Laser(s) represents distance sensor seeing time, “Stop(s)” represents the stopping time after distance sensor “ Backward(s)” represent pesticide time. Also “Laser”, ”Front sensor” and “Backward sensor” cells placed on screen and related with PLC sensor inputs could check the sensor operating when vehicle stops.

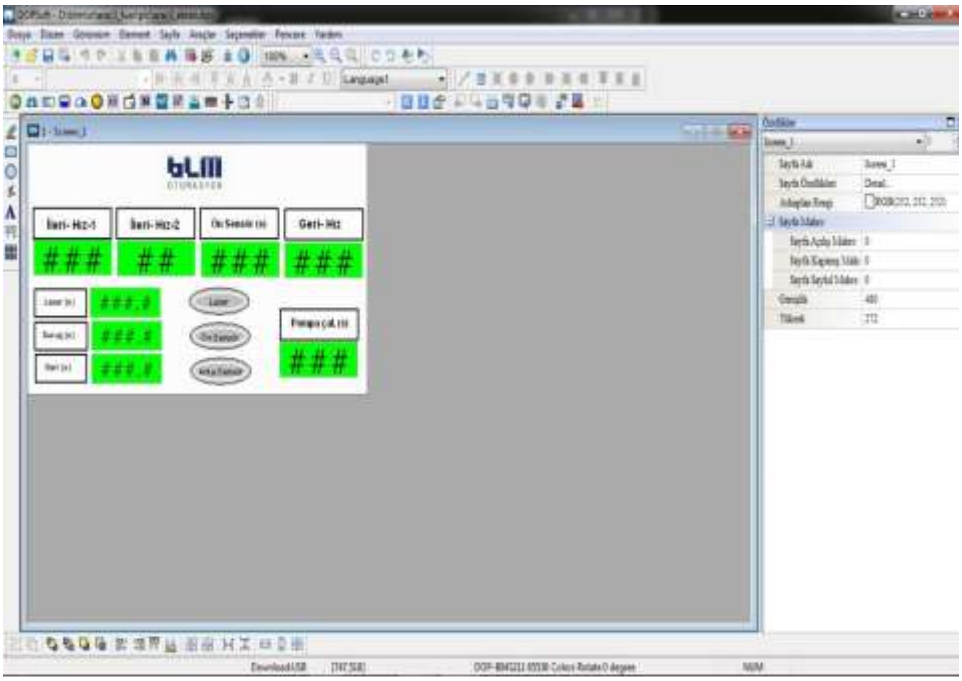


Figure 4.6 Screen software

4.4 Distance Sensor

Distance sensors can be ideal for collision avoidance, level measurement for liquids and solids, conveyor belt profiling, proximity detection, positioning and equipment monitoring, or even altimetry applications.

They are used where detection of small objects or precise positioning is required. Distance sensors have a small angle of aperature with a high energy density and thus a beam diameter which is almost unchanged throughout the entire range. This results in a tightly focused, almost parallel light beam that can detect very small objects at long ranges.

Main using area of distance sensor can be seen below:

Level Measurement

- Tall narrow bins
- Complex infrastructure inside bins (ladders, agitator blades, etc.)
- Non-intrusive measurements (through sight glass)
- Plastic pellets, slurries
- Outdoor river/stream monitoring
- Waste water treatment
- Lock level
- Stockpile height
- Molten metal level
- Ore pass and loading pocket level

Positioning and Detection

- Overhead crane
- Crane avoidance
- Tripper car
- Distance between vehicles (mounted in vehicle)

- Steel slab detection and positioning
- Pipe/tree length cutting system
- Camera focusing
- Surveillance detection and camera focusing
- Vehicle profiling
- Fixed point traffic monitor (speed, profiling, length, DBC)
- Truck loading system
- Parking garage system (open spots, illegal parking)
- Bridge height clearance
- Ship docking
- Targeting systems
- In-flight refueling

As can be seen in the market there are a wide variety of distance sensors. In this study, end of the row has been spotted with the distance sensor. And a distance sensor connection diagram is given in Figure 4.7.

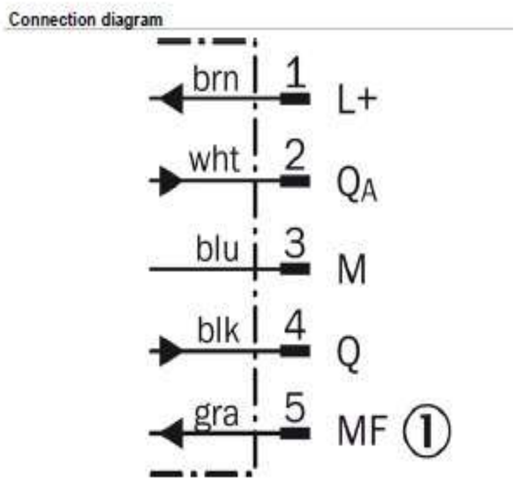


Figure 4.7 A distance sensor connection diagram

4.5 Limit Switch

Limit switch is an electrical key which changes its contacts, if a moving mechanism touches to switch. If contact of limit switches is changed, the open key closes or closed key opens and an electrical circuit opens or closes.

Limit switches consist of generally normally open (NO) and normally closed (NC) snap action contacts. There is also limit switches, those consist of different number of contacts and different open, close variations.

This type of switches has spring return mechanisms. When a force is applied to switch, contacts change positions. When force is removed, the switch turns back to its old condition. Also there are limit switches which needs resetting with hand, when force is removed.

In this study position switches and level switches are used.

4.5.1 Position Switch

In this study position switch is used to stop the vehicle. Connection and electrical scheme of the switch is given at Figure 4.8 and Figure 4.9.

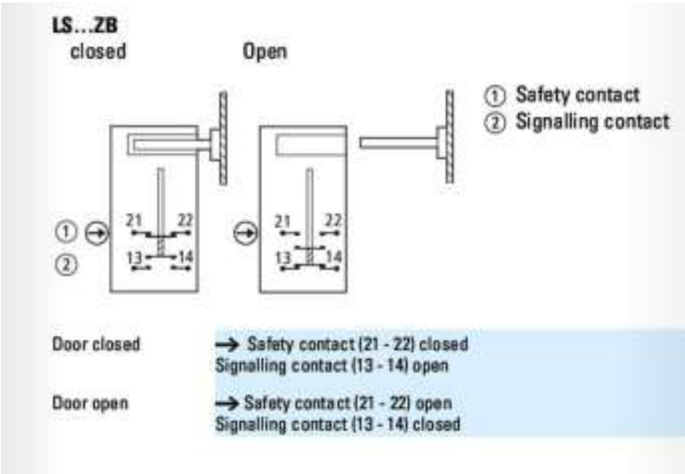


Figure 4.8 Contacts of the switch

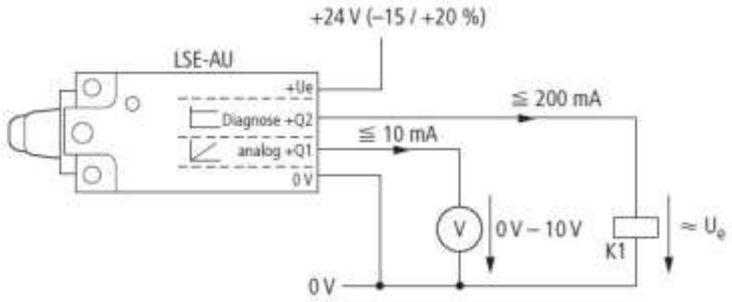


Figure 4.9 Electrical diagram of the switch

At automation of vehicle function of this switch senses the stopper at the end of line and the pipe at first row at the beginning of the hall, so the switch ensures stopping of vehicle. 21 and 22 numbered NO gates which are shown in Figure 4.8 are connected to ground and 24 Volt on PLC. When sensor senses the pipe rail, NO gates turn to NC; PLC senses and transmits that change to the motor driver, so motor stops.

4.5.2 Level Switch

In this study; this sensor is used for the measurement of the tank level. Sensor has two contacts and their condition (NO or NC) is changed with assembling position.

At the automation, sensor contacts assembled as NC, ground and 24V connections are established. When tank is filled, NC contact sends signals to PLC continuously. When the tank is empty, latch of the sensor drops and contact is opened, so the signals which has been sent to PLC, are cut. Due to that, warning light on the panel turns on. When the warning light is on, even if the push button is pressed, the vehicle does not move.

CHAPTER FIVE
TEST AND REVISION

Field tests of the manufactured vehicle have been conducted in Agrobay Seracılık. The test field is located in the north-south direction and its area is 10000 square meters. The operating instructions have been explained to the operators before the application as shown in Figure 5.1.

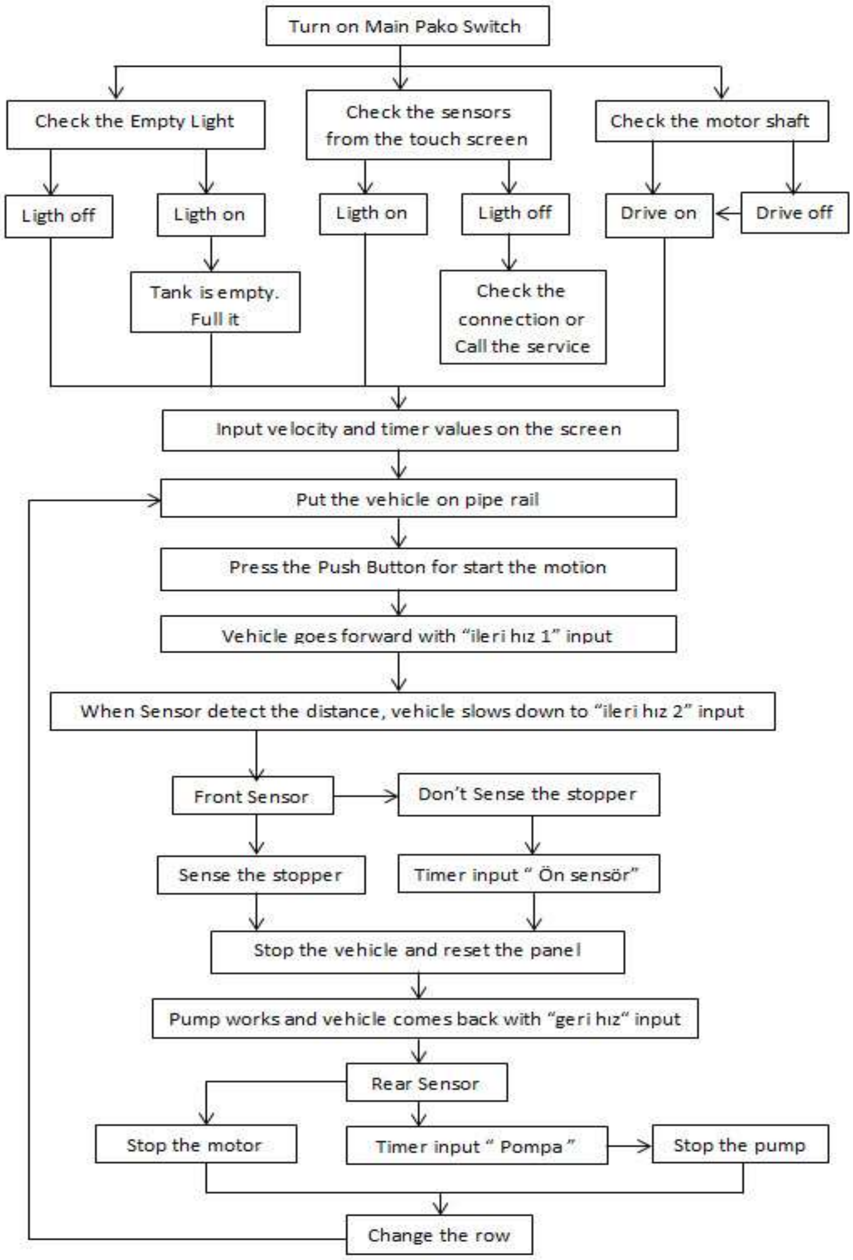


Figure 5.1 Instruction manual of the flow chart

5.1 Field Tests

According to the chart, first main switch on the panel is turned on and energy is supplied to the system from the batteries. Sensors and empty light are checked. If Light is on, tank is filled. Motor shaft is positioned drive on manually with lever arm. After that, the appropriate velocity and stand-by timings for the pesticide are entered to the screen which allowed the vehicle to be ready for usage as seen in Figure 5.2. The position of the vehicle before its movement and when it has been placed into the row can be seen in Figure 5.3. Push button is pressed to start the motion. Vehicle goes forward with the “ileri hız 1 “ input and with the distance detection of the sensor, vehicle slows down to “ ileri hız 2 “ input. Vehicle stops at the end of the row with sensor or timer. Next; pump work and vehicle comes back with “geri hız” for spraying as shown in Figure 5.4. When rear sensor senses the pipe, motor is stopped and according the pump timer, spraying is closed. Finally the changing row of the vehicle by the operator through the caster wheels can be seen Figure 5.5.

Figure 5.2 Screen inputs

Figure 5.3 Start position of the vehicle

Figure 5.4 Spray image

Figure 5.5 Motion between rows

Due to the inclined structure of the greenhouse, the sensor distances and the standby timings at the end of the row for both north and south sides has been entered to the screen and saved with the help of the PLC software. By this approach; the velocity, sensor distance and the standby times, which would improve the spraying quality, have been optimized and the most appropriate values have been defined. Furthermore, the chart that is linked for each table is given in the next graph. The velocity values are selected between the intervals which are assigned by the PLC.

While testing, forward motion, spraying motion and distance sensor sense times have been measured. This test has been repeated for south and north sides with different control inputs and recorded as below in the table 5.1, 5.2, 5.3, 5.4.

Table 5.1 First south side test data

	Row No	Sensor Time	Spray Time	Forward Time	
Velocity:900 Sensor Distance:5.5m Timer:6s	1	37,4	51	43,4	South Side
	2	37,1	50,7	39,1	
	3	37,1	50,3	43,1	
	4	36,7	50	42,7	
	5	36,4	50,1	42,4	
	6	36	49,4	42	
	7	36	49,3	42	
	8	35,4	49,3	41,9	
	9	36,4	50,2	42,4	
	10	36,1	50	42,1	
	11	34,9	48,6	40,9	
	12	35,6	49	41,6	
	13	35,6	48,8	41,6	
	14	35,6	49	41,6	
	15	35,4	48,2	41,1	
	16	35	48,3	41	

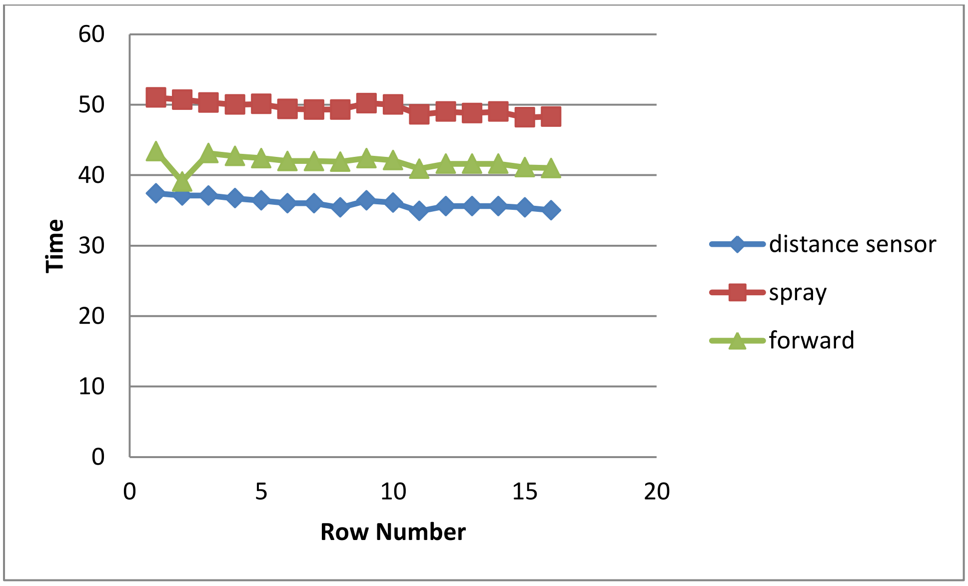


Figure 5.6 First south side test data graph

Table 5.2 Second south side test data

	Row No	Sensor Time	Spray Time	Forward Time	
Velocity:850 Sensor Distance:6.5m Timer:7s	1	39,8	49,1	45,9	South Side
	2	38,6	49	41	
	3	38,4	49,4	45,4	
	4	38,2	49	45	
	5	37,6	48,7	44,6	
	6	37,4	48,6	44,4	
	7	37,7	47,7	44,7	
	8	38,1	47	45,6	
	9	37,3	48,6	44,3	
	10	37,4	48,1	44,4	
	11	38,1	49,3	42	
	12	37,5	48,8	44,5	

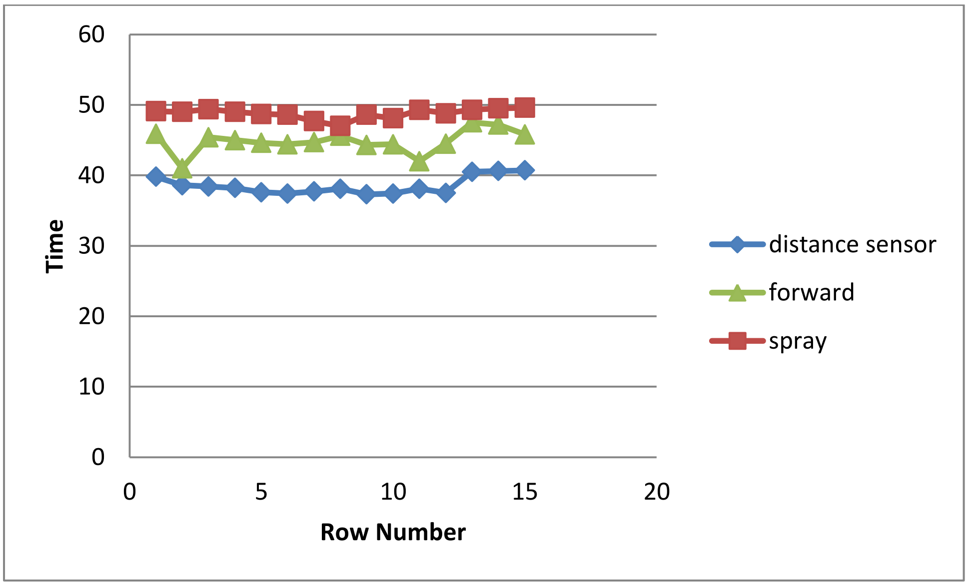


Figure 5.7 Second south side test data graph

Table 5.3 First north side test data

	Row No	Sensor Time	Spray Time	Forward Time	
Velocity:850 Sensor Distance:6.5m Timer:9s	1	37,6	49,3	46,6	North Side
	2	37,3	48,9	46,3	
	3	38,3	50,4	47,3	
	4	38	50,4	44,7	
	5	37,7	50,3	46,6	
	6	37,8	50,1	46,8	
	7	37,8	50,2	46,8	
	8	37,5	49,7	46,5	
	9	38,7	51,4	47,7	
	10	38	50,2	47	
	11	38	50,2	47	
	12	38,1	51,3	47,1	
	13	39,9	52,9	48,9	
	14	39,5	52,6	48,5	
	15	40,2	53,3	49,2	
	16	39,7	53,1	48,7	

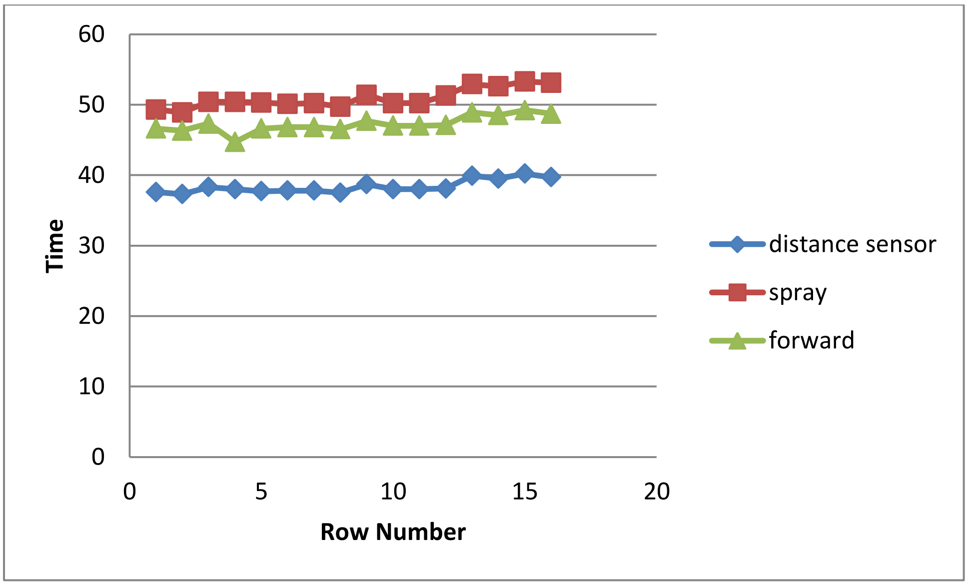


Figure 5.8 First north side test data graph

Table 5.4 Second north side test data

	Row No	Sensor Time	Spray Time	Forward Time	
Velocity:850 Sensor Distance:6.5m Timer:9s	1	39,8	53,3	48,8	North Side
	2	39,7	53,3	48,7	
	3	39,7	53,4	48,7	
	4	39,7	53	48,7	
	5	40	53,2	49	
	6	39,7	52,5	48,7	
	7	39,6	53	48,6	
	8	39,6	52,7	48,6	
	9	39,5	52,5	48,5	
	10	39,5	52,9	48,5	

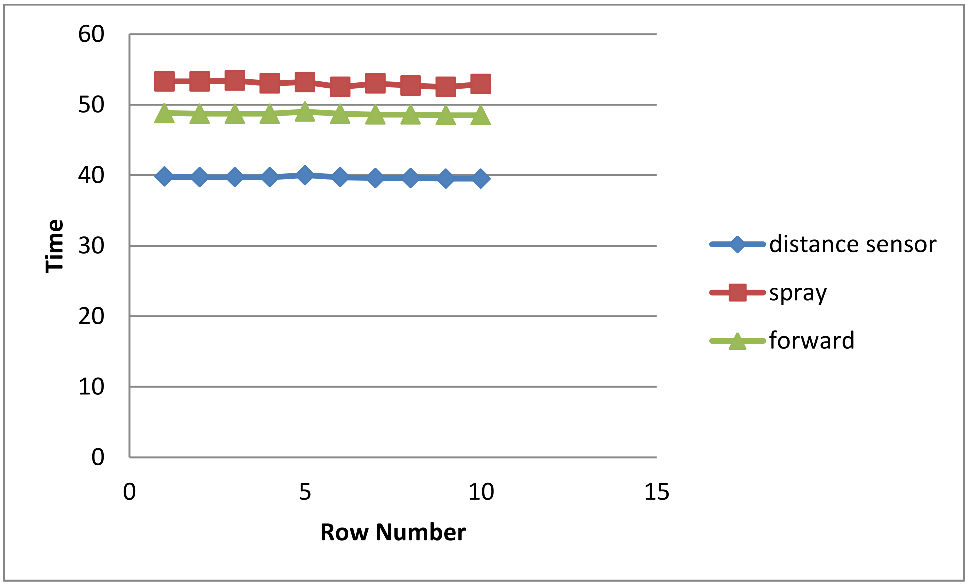


Figure 5.9 Second north side test data graph

5.2 Evaluation of the Test

During tests, acquired data are given below:

- As it can be seen from the Table 5.1, 5.2, 5.3 and 5.4, the velocity changes according to the slope of the greenhouse, the position of the pipe rails and the infrastructure issues. The standby time at the end of the row varies for each row.
- The vehicle sometimes stops its movement and starts spraying before it reaches the end of the row due to an early detection of an object by the distance sensor.
- When the vehicle gets out of the row, it shuts down early; therefore the spraying at the beginning of the row cannot be conducted efficiently.
- The vehicle wanders to left and right on the pipe rail.
- The caster wheels hits to the hall concrete when the vehicle gets out of the row, which frequently leads to a broken caster wheel.
- It is hard for the operator to transfer the vehicle from one row to another when the tank is full.
- The frequent refilling requirement causes a waste of time.
- The batteries die quickly in a long-term usage.
- The cable connections and the components inside the control panel come off because of the high amount of vibration that affects the control panel.
- The nuts and bolts are disassembled because of the vibration.
- Stoppers do not exist in some row ends, which prevents the inductive sensor from detecting the stopper and leads to a crash of the vehicle to the row end.
- The vehicle is damaged when it is transported from one greenhouse to another as the motor is located at the bottom of the vehicle.
- The jaws of the forklift do not fit underneath the vehicle which causes difficulties in transportation.
- Automation failures occur often because of the vibration, temperature and corrosion.
- Deformations may occur on the vehicle as the pesticide is acidic.

According to the data, evaluations are given below:

- The values, that have been obtained according to the data from the Figure 5.6, 5.7, 5.8 and 5.9, are given below:

Table 5.5 Screen inputs

	South Side	North Side
Velocity	*900*	*850*
Sensor distance (m)	*5.5*	6.5
Stop time (s)	*6*	9

- The current vehicle finished one row in 3 minutes and jumps to the other row in 5 minutes. The new vehicle completes a row in 1.35 minutes and jumps to the other row in 12 seconds. The refilling time is 3 minutes.
- 100 liters of fluid can be filled into the tank that is located on top and 10 rows can be sprayed with this amount. The spraying of 10 rows lasts for 20 minutes.
- The new vehicle can finish spraying, when the current vehicle still has 2 more tunnels to go.
- Wet wheels and pipes cause aquaplaning and reduce the safety of breaking distance.
- Branches and leaves that are in the laser detection range should be removed.
- The pesticide can be applied by an operator to the unsprayed areas which are at the beginning of the rows by a manual spraying switch that has been added on the panel.
- The distance between the outer surfaces of the vehicles has been reduced so that the wandering of the vehicle on the pipeline could be avoided.
- The bearing of the caster wheels is done with a gas spring has been mounted which allowed the absorption of the forces, those occurred during the exit. However an extensive force causes a lockdown in the dampers thence, usage of two dampers or a stronger single damper may solve the issue.
- It has been worked on to increase the distance between the vehicle center of gravity and the control lever so that the movement between the rows could be eased.

- It has been assessed that a capacity increase of the tank to 200 lt. is suitable. However, this may require an additional motor power and cause a negative effect on the movement due to the extra weight.
- Instead of filling the pesticide from the main tank, it can be prepared inside the vehicle tank with small solutions.
- A drawer system has been integrated for the battery in order to increase the usage time by batter exchange capability.
- Control panel has been connected to the chassis with a flexible beam so that the panel can oscillate freely which reduces the affecting vibration. In this way, the transmission of the vibrations to the panel has been avoided.
- Spring nut washers and fibered nuts have been used to prevent the unfastening of nuts and bolts.
- The perception of the vehicle halt from the pipe has been fulfilled with a mechanical switch as the detection range and durability of the inductive sensors are low. A timer has been integrated to the software to stop the vehicle at the end of the row as an additional safety measure.
- Metal sheeting has been mounted underneath the vehicle with profile from the chassis to protect the motor from a possible damage.
- A similar approach of posts may be used for the forklift jaws to operate properly.
- A manual control has been integrated to the software as an addition and a folding ladder has been added so that an operator can step on it.
- It has been recommended that the vehicle should be cleaned after each spraying procedure to prevent the acidic damages.

5.3 Problems Encountered in Field Tests

Three main problem has been solved during the tests. First problem is the vibration on the electric panel. Second problem is the motor damage while transportation. Final problem is the fracture of the casters.

5.3.1 Panel Problem and Solution

Vibration on the panel is the big problem for the automation and the vehicle, When panel is fixed from the connection holes, all forces and vibrations from chassis are transferred to the panel. Electronic parts are damaged and automation system is out of order. Hence, a flexible beam has been designed between panel and chassis as shown in Figure 5.10.

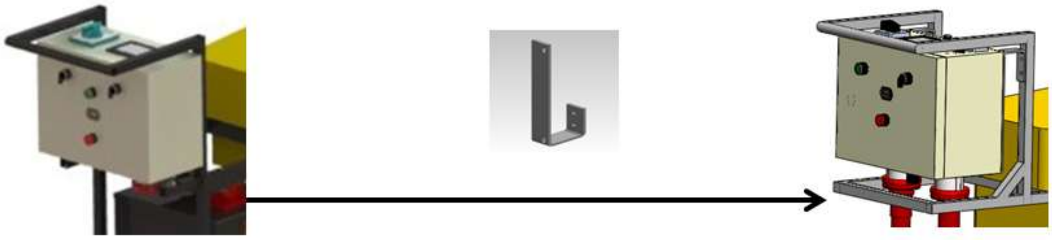


Figure 5.10 Panel vibration solution

Flexible beam is gain the flexibility to the panel. With the help of the flexible beam, when the vehicle hits anywhere or vibration effect causes, panel swings with the flexible beam so that electronic parts are protected from the external factors.

While deciding the flexible beam first static, impact and natural frequency analysis have beendone with CosmosWorks. For all analyses, assembly has been fixed from the chassis leg and analysis has been done for whole system. However, only panel side has been evaluated.

In static analysis, gravity force has been applied. For impact analysis one g force has been applied in the direction of motion like a hit to somewhere. In natural frequency analysis, only the frequencies of the panel are shown.

These analyses have been repeated for fixed panel and panel with flexible beam and results are as shown below:

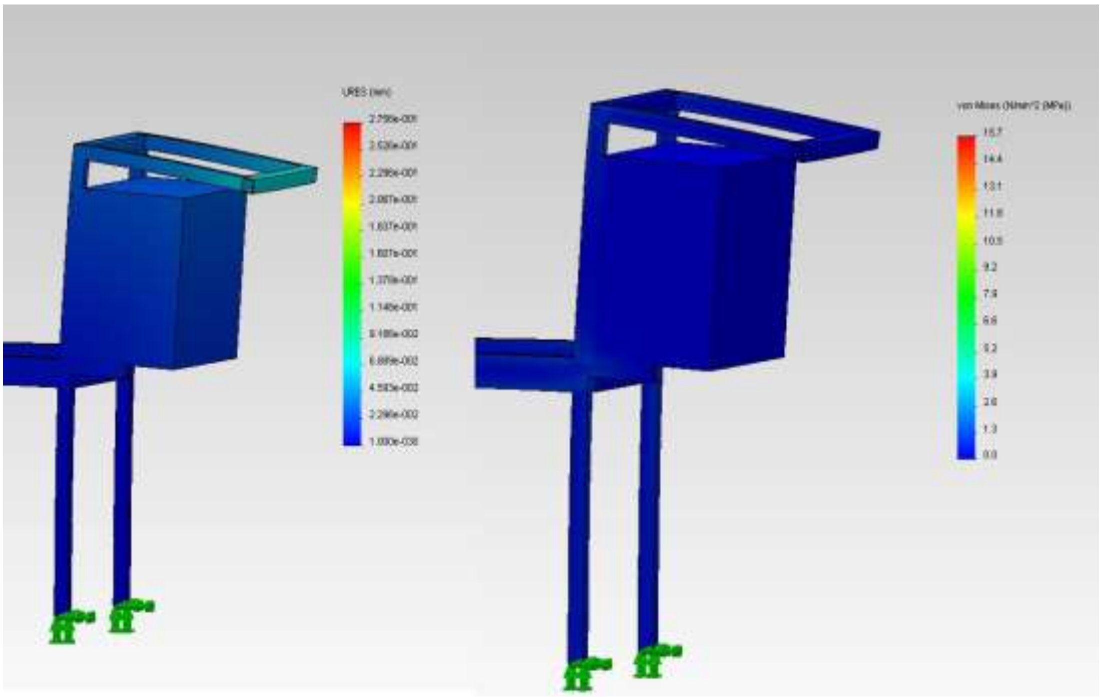


Figure 5.11 Fixed panel static analysis

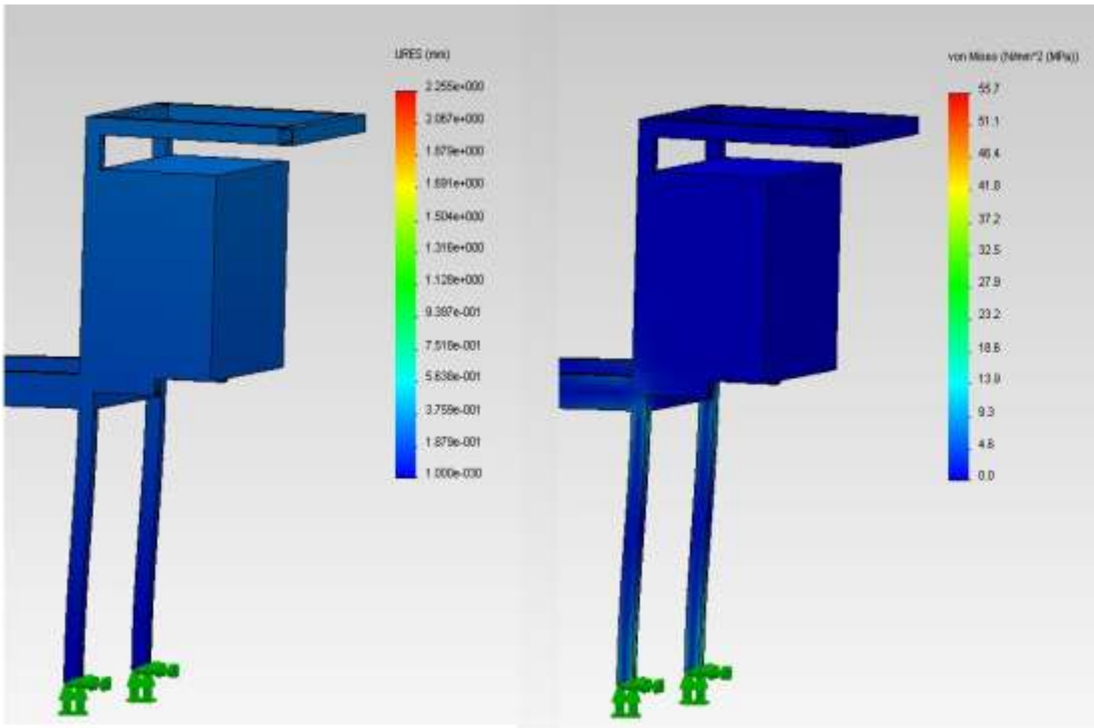


Figure 5.12 Fixed panel impact analysis

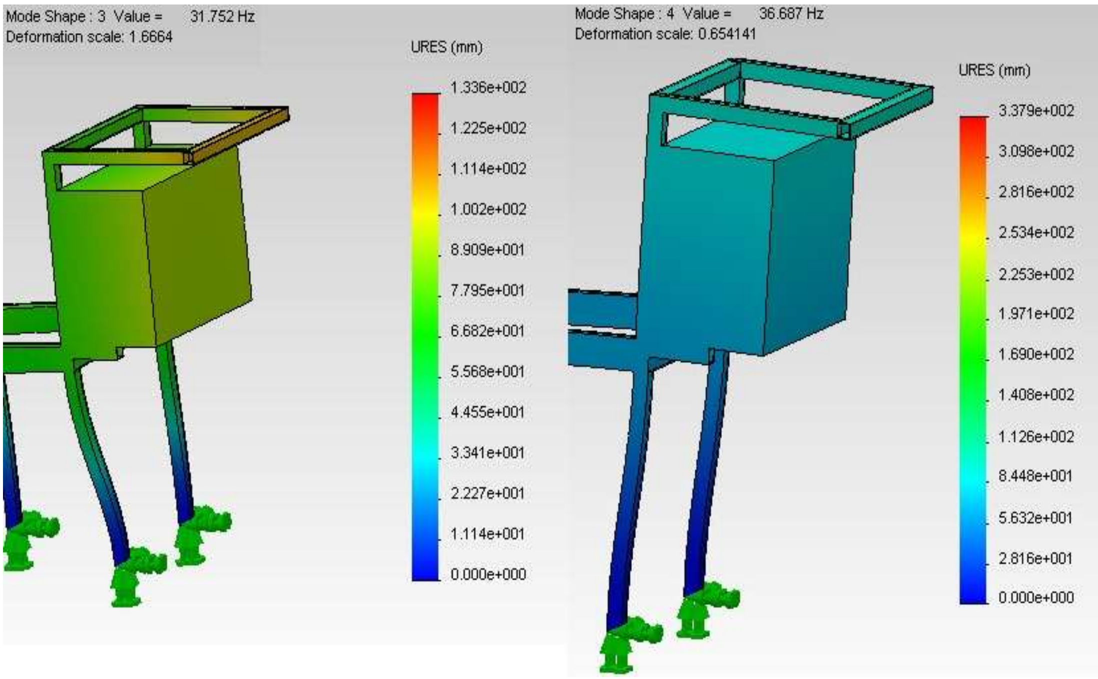


Figure 5.13 Fixed panel natural frequency analysis

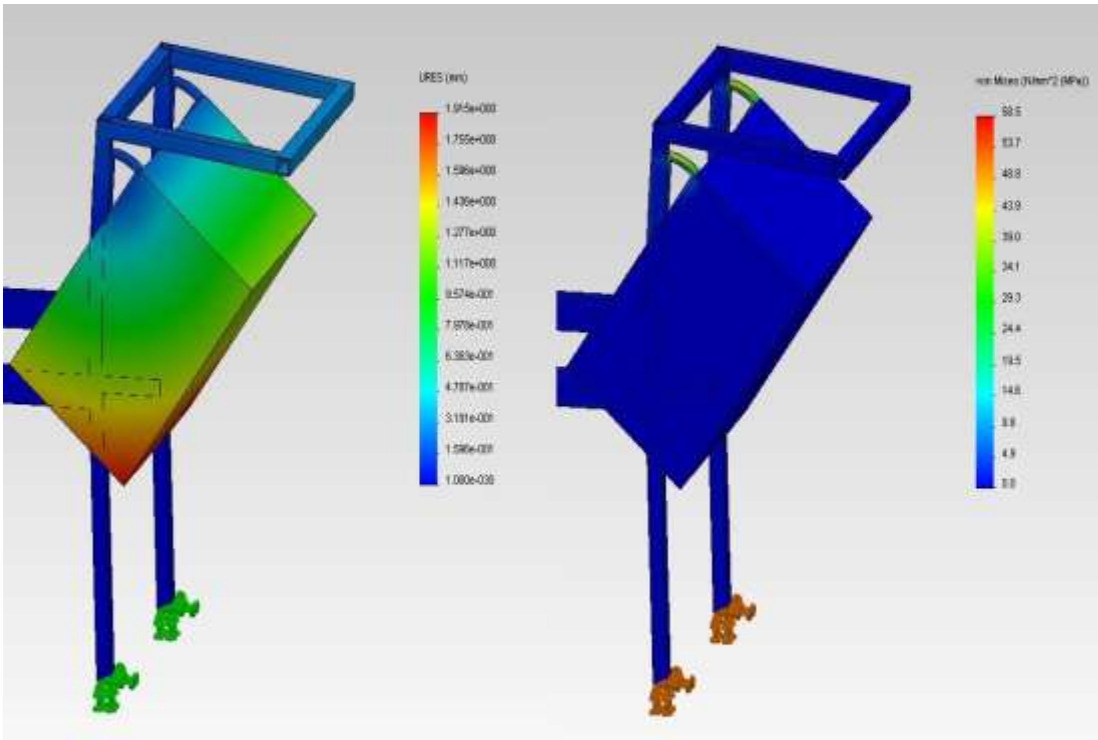


Figure 5.14 Panel with flexible beam static analysis

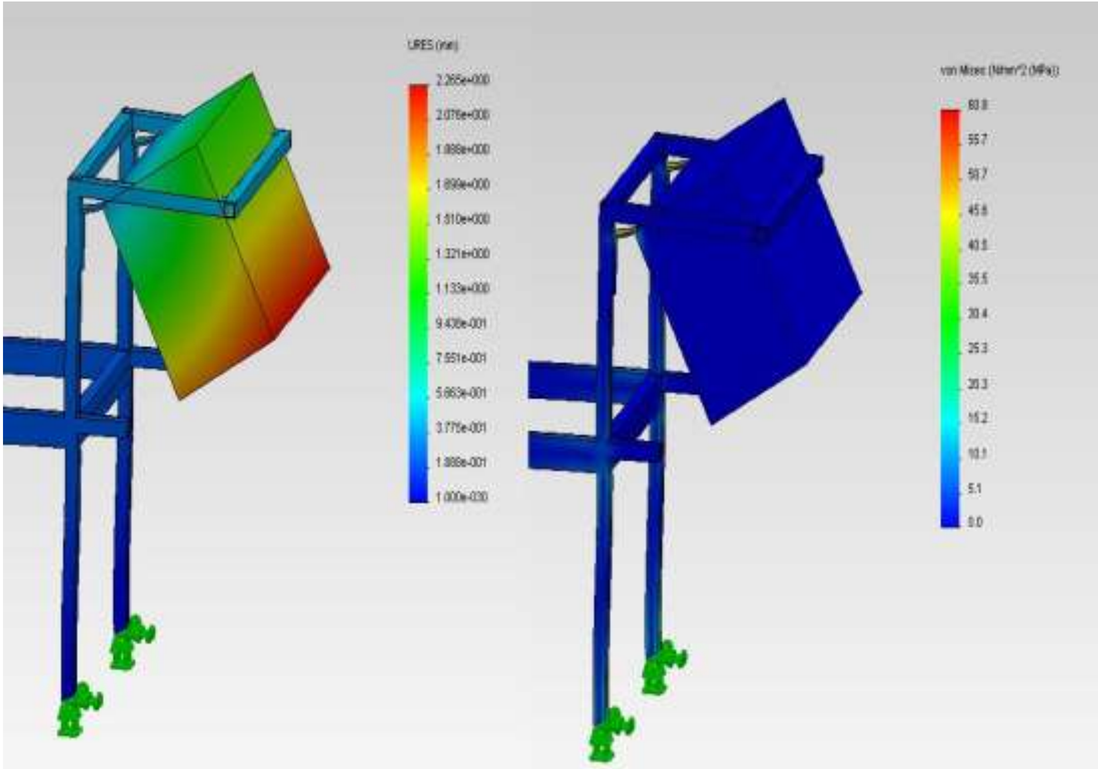


Figure 5.15 Panel with flexible beam impact analysis

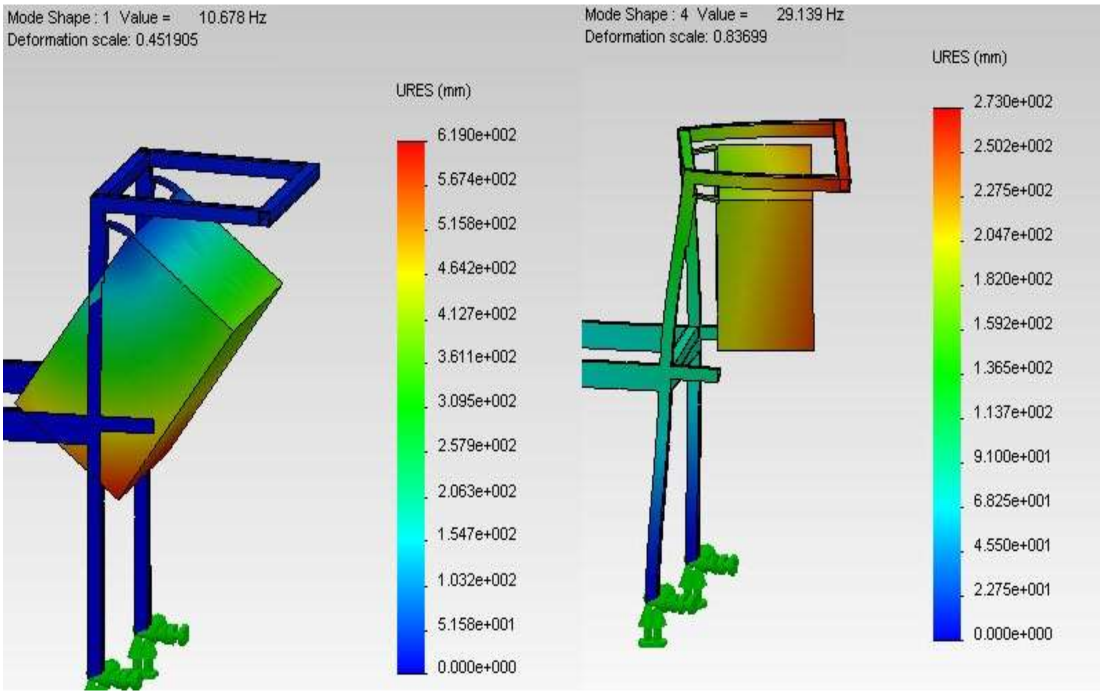


Figure 5.16 Panel with flexible beam natural frequency analysis

Compared static analysis in Table 5.6; natural frequency analysis in Table 5.7 are given below.

Table 5.6 Natural frequency analysis results for panel

	Fixed panel	**Panel with flexible beam**
	Freq Value (Hz)	Freq Value (Hz)
First Frequency	*31.752*	*10.678*
Second Frequency	*36.687*	*29.139*

Natural frequencies are decreased by flexible beam. Fixed panel always oscillates with chassis. But panel with flexible beam oscillates independently thus, forces which come from the chassis don't affect the panel.

Table 5.7 Static analysis results for panel

	Fixed panel		**Panel with flexible beam**	
	Stress (MPa)	Displacement (mm)	Stress (MPa)	Displacement (mm)
Static Analysis	15.7	0.27	58.5	1.91
Impact Analysis	55.7	2.25	60.8	2.26

Stress values are reduced by panel design and displacements are nearly the same and these results are acceptable for AISI 1020 material.

But to increase natural frequency values and decrease the displacement and stress values; width of the flexible beam can be changed. For example it can be decreased 5 to 10 mm. Despite those; the given dimensions and design are satisfying the solution.

5.3.2 Motor Problem and Solution

The vehicle is damaged when it is transported from one greenhouse to another as the motor is located at the bottom of the vehicle. So metal sheeting has been mounted underneath the vehicle with profile from the chassis to protect the motor from a possible damage as shown in Figure 5.17

Figure 5.17 Motor protection

5.3.3 Caster Problem and Solution

The caster wheels hits to the hall concrete when the vehicle gets out of the row, which frequently leads to a broken caster wheel. So The bearing of the caster wheels linked to the chassis with a gas spring which allowed the absorption of the forces, those occurred during the exit as given in Figure 5.18.

Figure 5.18 Caster with gas spring

For selection of the spring force two main criterion is considered. When the caster hits the hall spring must be closed to absorption the reaction force. And while moving the vehicle on the hall, spring must not close with the weight of the vehicle. So required calculation has been done as given below according to:

$$\sum M = 0$$

$$F_1 \times x_1 + F_2 \times x_2 + \cdots = 0 \quad (5.1)$$

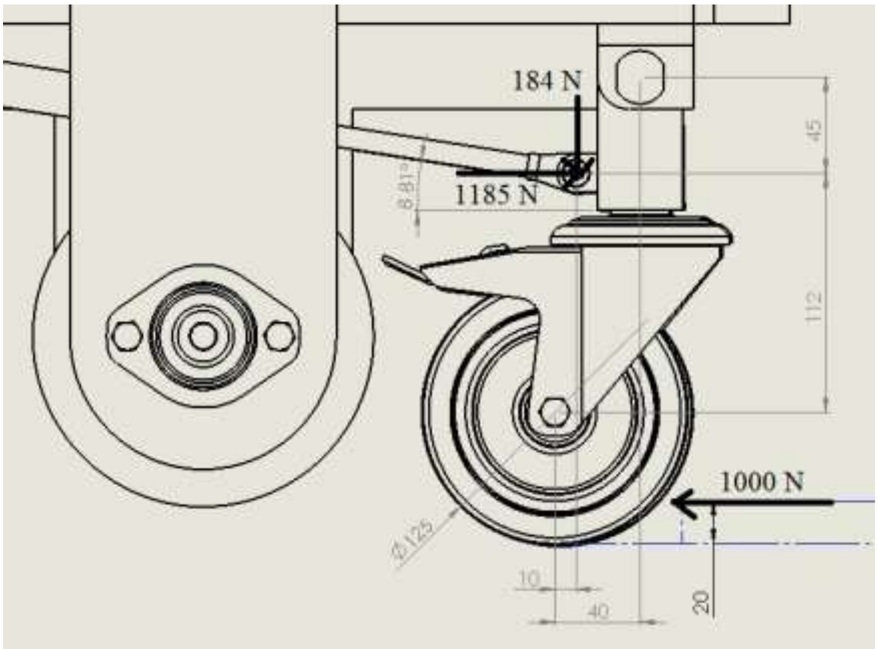


Figure 5.19 Caster position one

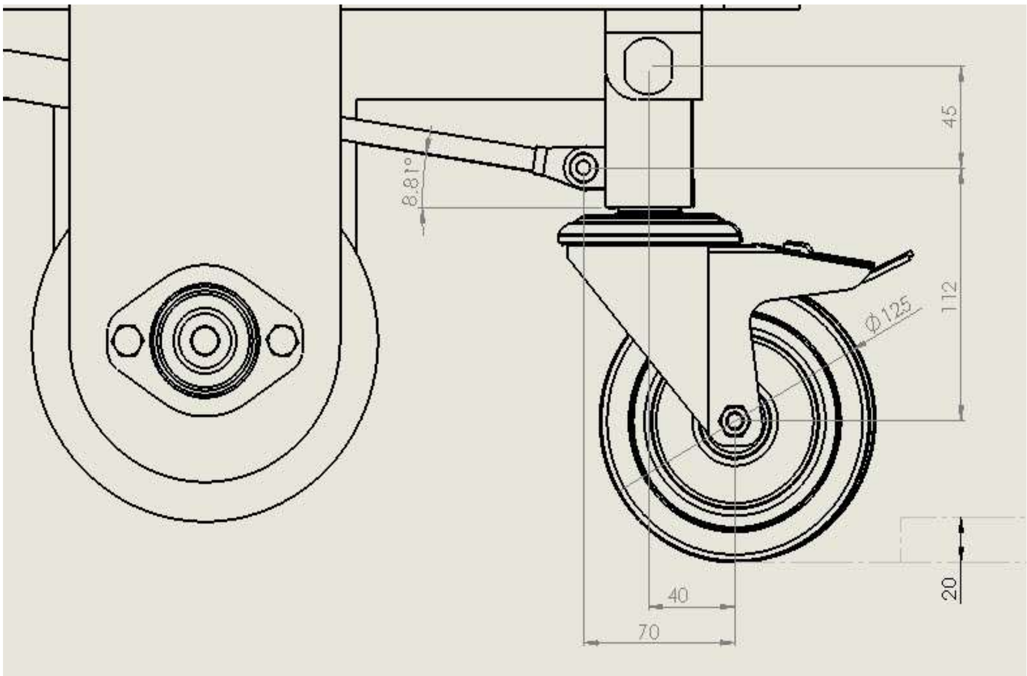


Figure 5.20 Caster position two

1200 N gas spring has been selected. Cause of the vehicle weight, average 1000 N is applied to caster. Reaction force is selected 1000 N, too. And calculations have been done free body diagram which is given in Figure 5.19 and 5.20.

$M_{spring} = 1185 \times 0.045 + 184 \times 0.03 = 58.845\ Nm$

$M_{reaction\ force} = 1000 \times 0.1995 = 199.5\ Nm$

$M_{spring} < M_{reaction\ force}$, thus spring closes.

$M_{weight} = 1000 \times 0.04 = 40\ Nm$

$M_{spring} > M_{weight}$, thus spring don't close. It works as a fixed beam.

Hence, 1200 N gas spring is suitable for solution of the problem.

CHAPTER SIX
RESULTS AND DISCUSSIONS

6.1 Static Analysis Results

CosmosWorks results are given in Table 6.1

Table 6.1 CosmosWorks static analysis results

Part Name	Max Von-Mises Stress (MPa)	Max Displacement (mm)
Front axle	*55.8*	*0.028*
Rear axle	*66*	*0.016*
Main chassis	*26.9*	*0.108*
Tank chassis	*40.8*	*0.405*
Caster house	*53.2*	*0.006*
Panel prop	*147.2*	*1.647*
Manual ladder	*178*	*0.476*
Trolley	*19.7*	*0.289*

AISI 1020 material has been applied to all parts. AISI 1020 properties are given at Appendix, Figure 7.7. Material yield strength is 249. 8 MPa, Tensile strength is 394.7.

Due to unknown dynamic forces, for static analysis, 100 MPa is selected as the maximum boundary of the stress value for safety.

Stresses are for the situation under the yield strength for front axle. The maximum stress, 55.8 Mpa is located near the maximum force where has been painted red in Figure 3.6. Thus, the part is suitable for the vehicle. A diameter decrement can be applied. Maximum displacement occurs between the forces. This area is covered by wheel, therefore; 0.028 mm is not important for this part.

Max stress, which has been located near the middle fixed fixtures; is simulated 66 MPa for rear axle. In other words, axle is suitable for production. Max displacement value 0.0165 mm which is colored in red can be ignored.

Max stress for main chassis, 26.9 MPa is located around the center of mass, between the wheels. Max value is less than 12 times from the yield strength. Displacements are located at the middle of the vehicle, cause of the center of mass effect. 0.1 mm is an acceptable value for a 1.5 meter vehicle.

40.8 MPa stress for the thank chassis is ideal for the production. Vertical prop position affects the stress value widely. Max displacement occurs between vertical legs as 0.4 mm. If vertical prop has been close to each other, displacement would be less than the present value.

Max stress on the caster house occurs in the pin hole to the direction of the force. Part is suitable with 53.2 max stress. Displacement, which has been located at the bottom of the hole to the direction of the force, are seen. Results are suitable for this application.

For panel flexible beam, 147.2 MPa may be dangerous for the fatigue. Stress areas occur in the bolt connection holes. But value is below the yield strength. In order to reduce the effect of the impact and vibration over the panel, flexible beam must be flexible. Thus; 1 mm displacement value is considerable. For this part, displacement values must be as much as enough.

Max stress on the ladder occurs at the pin holes of the hinges. 178 MPa strain may be a problem in long time usage. But it can not constitute a problem as there is no space for two operators. For safety, the force has been applied as if two operators are standing. Displacements occur far away from the hinge as expected. 0.47 mm displacement may be ruled out.

ANSYS analysis results has been seen as in Table 6.2

Table 6.2 ANSYS static analysis results

Result Type	150 lt Tank	200 lt Tank
Maximum stress (MPa)	*28*	*42*
Minimum stress (MPa)	*1.8*	*2.7*
Maximum displacement (mm)	*0.591*	*1.4*

Maximum stress occurs on the tank chassis with 28 MPa as shown in Figure 3.22. for 150 L tank capacity. For 200 L tank capacity maximum stress goes up to 42 MPa. Displacements on the 200 liter tank are over the 1 mm. So this is the unwanted situation.

6.2 Modal Analysis Results

Cosmosworks natural frequency analysis results are given below in Table 6.3

Table 6.3 CosmosWorks natural frequency analysis results for main assembly

Mode Shape	Natural Frequency
1	*12.925*
2	*21.483*
3	*26.823*

First mode, which is 12.925 Hz, oscillates around the z coordinate axis at the top of the boom as expected. Boom is a very long and narrow part. Especially due to the two fixed areas to chassis, frequency is decreased. So natural frequency analysis must be compared with the ANSYS analysis.

Second mode, which is 21.483 Hz oscillates around the x coordinate axis at the top of the boom again. Nonetheless, frequency value is acceptable.

Third mode, which is 26.823 Hz, oscillates on the z coordinate axis at the top of the boom with the tank. Frequency is at normal level.

ANSYS natural frequency analysis results are given below in Table 6.3

Table 6.4 ANSYS natural frequency analysis results

Tank Capacity (lt)	Mode Shape	Natural Frequency (Hz)
150	*1*	*9.263*
	2	*9.405*
	3	*10.804*
200	*1*	*8.348*
	2	*9.331*
	3	*9.969*

First and second frequencies , which occur on the boom, are nearly 9.5 Hz and first frequency oscillates around the z axis, second frequency oscillates around x axis. Third frequency which occurs on the boom and tank chassis, is nearly 11 Hz and it oscillates around the z axis.

Mass increment affects only the value of the frequency. It decreases the frequency value. Hence; 150 liter tank is used at the design.

6.3 Motion Analysis Results

6.3.1 CosmosMotion Analysis

Dynamic analysis results for the motor are given below in Table 6.5.

Table 6.5 CosmosMotion results

for $a = 0.5\ m/s^2$ and $V_{max} = 2\ m/s$	Value
Power consumption (W)	*460*
Motor torque (Nm)	*10.447*

As seen as in Figure 3.35, because of the initial conditions and static forces, values (Figure 3.34) are not initiated from the zero point.

Power consumption has been 460 W max for acceleration. Motor torque to move the wheels has been 10.44 Nm.

Finally the data points which are inputs for radial velocity (deg/sec) are correct as seen in time history velocity (mm/sec).

6.3.2 Analysis with MATLAB

Matlab is a high-level language interactive environment for numerical computation, visulation and programming.

6.3.2.1 Motor

According to data from present trolley, pre-design and users, initial inputs are like shown below Table 6.7.

Table 6.7 Initial inputs

Acceleration (a)	0.5 m/s²
Forward velocity (ϑ_f)	2 m/s
Spraying velocity (ϑ_s)	1 m/s
Maximum angle of climb (α)	0°
Rolling resistance (ρ)(constant)	0.015
Mass of the vehicle (m)	400 kg
Gravity acceleration (g)	9.81 m/s²
Average motor efficiency (μ_m)	0.8
Wheel radius (r) and diameter (R)	45 mm – 90 mm
Motor cycle (n_m)	3200 rpm
Motor ratio (i_m)	32

Movement Force (F) – to move the vehicle, opposite force of the total resistance force which affects the vehicle. Total motion force equation is given below and represented in equation 6.1. (Prof. Dr. Nusret Sefa Kuralay, 2008)

$$F_{T\ acceleration} = m \times a + m \times g \times sin\alpha + m \times g \times cos\alpha \times \rho \quad (6.1)$$

$$= 400 \times 0.5 + 400 \times 9.81 \times sin0° + 400 \times 9.81 \times cos0° \times 0.015$$

$$= 200 + 0 + 59 = 259\ N$$

$$F_{T\ constant\ velocity} = m \times g \times cos\alpha \times \rho \quad (6.2)$$

$$= 400 \times 9.81 \times cos0° \times 0.015 = 59\ N$$

Power Consumption (P) – power which the motor need for moving the vehicle.

$$P_{need} = F_{T\ acceleration} \times \vartheta_f \quad (6.3)$$

$$= 259 \times 2 = 518\ W$$

$$P_{motor} = P_{need} \div \mu_m \quad (6.4)$$

$$= 518 \div 0.8 \cong 650\ W$$

Torque (T) – needed moment for turning the wheels. It can be calculated from wheels and power consumption.

$$T_{wheel} = F \times r = 259 \times 0.045 = 11.665\ Nm \quad (6.5)$$

$$P_{need} = T_{motor} \times \omega(angular\ velocity\ of\ wheel) \quad (6.6)$$

$$T_{motor} = 518 \div \left(\frac{2000}{\pi \times 90}\right) = 11.66\ Nm$$

$T_{wheel} \cong T_{motor}$, thus calculation is correct.

6.3.2.2 Gears

For turning wheels by 2 m/s, motor ratio must be changed with gears which have different number of teeth. So gear ratio can be calculated like shown below:

$$n_{wheel} = \vartheta \div S\ (round\ of\ the\ wheel) \quad (6.7)$$

$$= \left(\frac{2000}{\pi \times 90}\right) \div 60 = 424{,}41\ rpm$$

$$n_{reduction} = n_m \div i_m \tag{6.8}$$

$$= 3700 \div 32 = 115.625\, rpm$$

$$i_{gear} = n_{wheel} \div n_{reduction} \tag{6.9}$$

$$= 424.41 \div 115.625 = 3.67$$

6.3.2.3 Battery

To calculate the battery requirement, work time and power consumption must be known. The data required is given below in Table 6.8

Table 6.8 Data for battery need

Battery voltage (V)	12 V
Forward velocity (ϑ_f)	2 m/s
Forward time (t_f)	21 s
Spraying velocity (ϑ_s)	1 m/s
Spraying time (t_s)	48 s
Acceleration (a)	0.5 m/s^2
Acceleration time (t)	4 s (forward) , 2 s (spraying)
Motion force ($F_{constant\ velocity}$, $F_{acceleration}$)	*59 N, 259 N*
Pump efficiency (μ_p)	0.55
Nozzle pressure (p)	10 Bar
Quantity of pesticide (L)	12 L
Length of the row (l)	50 m
Battery efficiency (μ_b)	0.8

Greenhouse structure: 1 tunnel has 12 rows. One vehicle is spraying 9 tunnels. In other words, $9 \times 12 = 108$ rows.

Motor Requirement – F_{motor} = 259 N

$$Energy(E) = Force(F) \times Velocity(\vartheta) \times cycle(\varphi) \times time(t) \tag{6.10}$$

$E_1 = 259 \times 1 \times 2 \times 2 = 1036\, Ws$ (spraying acceleration)

$E_2 = 259 \times 2 \times 2 \times 4 = 4144\ Ws$ (forward acceleration)

$E_3 = 59 \times 2 \times 1 \times 21 = 2478\ Ws$ (forward constant velocity)

$E_4 = 59 \times 1 \times 1 \times 48 = 2832\ Ws$ (spraying constant velocity)

$E_T = 1036 + 4144 + 2478 + 2831 = 10490\ Ws$ (requirement for one row)

$E = \frac{10490 \times 108(total\ row)}{3600} = 314.7\ Wh$

$$Battery\ capacity\ (U) = Energy\ (E) \div Voltage\ (V) \quad (6.11)$$

$$U_{motor} = 314.7 \div (2x12)(two\ serial\ connection)$$

$$\cong 15\ Ah$$

Pump Requirement – P = 10 Bar

$$Energy = Power \times work\ length \times time \quad (6.12)$$

$$Power\ (watt) = Pressure\ (Pascal) \times flow\ rate \quad (6.13)$$

$$Flow\ rate\ = \frac{liquid\ quantity}{flow\ time} \quad (6.14)$$

From 6.13 and 6.14

$$P_{need} = p \times Q = 10x10^5 \times \frac{12 \times 10^{-3}}{50} = 240\ W \quad (6.15)$$

$$P_{pump} = P_{need} \div \mu_p = 240 \div 0.55 \cong 440\ W \quad (6.16)$$

$E = 440 \times 50 \times 108 = 2376000\ Ws = 660\ Wh$

$U_{pump} = 660 \div 24 = 27\ Ah$

Finally,

$U_{need} = 27 + 15 = 42\ Ah$

$$U_{total} = U_{need} \div \mu_b = 42 \div 0.8 = 52.5\ Ah$$

Table 6.9 Calculation Results

Data Name	Value
Acceleration motion force	*259 N*
Constant velocity motion force	*59 N*
Gear Ration	*3.67*
Motor torque	*11.6 Nm*
Motor power consumption	*650 W*
Pump power consumption	*440 W*
Battery capacity	*52.5 Ah*
Payload on the front axle	*212 kg*
Payload on the rear axle	*188 kg*
Payload on the front wheel (two bearings)	*8.5 kg – 97.5 kg*
Payload on the rear wheel (two bearings)	*4 kg – 90 kg*
Payload on the front axle housing (two bearings)	*26 kg – 80 kg*
Payload on the rear axle housing (two bearings)	*23 kg – 71 kg*

6.4 Analysis Consideration

Calculations by MATLAB and CosmosWorks values are similar to each other. Maximum value for power consumption is 518 W. With efficiencies, 750 W motor can be selected and it must give 12 Nm on the working revolution speed. Motor splines are given at Appendix in Figure 7.3

Table 6.10 Requirement results

Data Name	Analysis with MATLAB	CosmosWorks
Power consumption (W)	*518*	*460*
Motor torque (Nm)	*11.6*	*10.447*

CosmosWorks and ANSYS results are compared each other. CosmosWorks static results and ANSYS natural frequency results are approved for real world.

Static analysis results for whole vehicle are given in Table 6.11 comparatively.

Table 6.11 Static Analysis Results

Result Type	CosmosWorks	ANSYS
Maximum stress (MPa)	*19.7*	*28*
Maximum displacement (mm)	*0.289*	*0.591*

As seen that, ANSYS results are higher than the CosmosWorks results. The reason for this is that ANSYS uses beam analysis and CosmosWorks uses Solid Analysis.

As stress max value is 100 MPa, 30 MPa is so under the maximum boundary. Thus; chassis profile sections and thickness of the parts can be reduced.

Natural frequencies results are as seen in Table 6.12

Table 6.12 Natural frequencies results

Analysis Program	Mode Shape	Natural Frequency (Hz)
CosmosMotion	*1*	*12.925*
	2	*21.483*
	3	*26.823*
ANSYS	*1*	*9.263*
	2	*9.405*
	3	*10.804*

As seen Table in ANSYS results looks like more realistic. Because of the boundary condition selection, frequencies may increase. Boom frequencies are critical as seen in Figure 3.29 and 3.30. So boom must be supported from the edges and thickness may be increased.

According to the entire results for detailed design, simulation results are used. Especially market parts selection is done according to the results. By power consumption results; 750 W motor is selected. According to the reaction forces, bearing units are indicated. Batteries are chosen for s suitable capacity of 80 Ah.

CHAPTER SEVEN
CONCLUSION

As a consequence of the developments in robotic technology, autonomous vehicles are becoming more advanced and they are being used in almost every branch of the industry. Considering the damp in greenhouses and the hazard of the agricultural pesticides to the human health, the demand for the autonomous vehicles became significant. Furthermore, semi and fully-automated systems allow reduction manpower and cost, thus the research project topics are headed towards these fields.

In this study, the design and production of the automatic spraying vehicle have been carried out under BLM Otomasyon Company. The predesign in SolidWorks has been fulfilled by using the data which have been obtained from the technical excursions and existing vehicles. According to this predesign, motion forces, bearing forces, battery requirement, motor power and torque requirements have been calculated with the mathematical formulas. After that, the static and natural frequency analysis for the critical components such as axle, chassis and bearing have been conducted with CosmosWorks. Additionally, these analyses have been made once more with the beam method by exporting the design dimensions to ANSYS with a Visual Basic based API software. The results, which have been obtained from these two different approaches, have been compared and results from CosmosWorks have been used in static analysis while results from ANSYS have been used in natural frequency analysis. Moreover, power and torque requirements have been calculated in CosmosMotion by applying the desired velocity-time profile.

Substantially, automated greenhouse vehicles can operate without a problem providing that they are used in a defect free operating environment. In the design of such a system, minimizing the size of the vehicle in order to prevent possible damages to the plants, light and durable chassis, a problem-free control panel, an efficient pump that can operate between the desired pressure and flow values, high quality nozzles are the fundamental factors.

In order to convert the vehicle to an autonomous one, a PLC unit has been integrated to the control unit, alongside with the motor driver. The inlet and outlet of the pipe have been detected with two mechanical sensors and a distance sensor has been used in order to detect the end of the rows through distance measurement. The velocity of the vehicle can be controlled by entering the velocity and stand-by timing to the control panel. The movement between the rows is directed by an operator by using the caster wheels which are located at the rear of driving wheels.

Field tests have been done. Vehicles receive a large amount of impact due to operator errors and the deficiencies in infrastructure. Hence, a gas spring is linked between caster and chassis. A major amount of vibration affects the control panel because of the geometric defects and bumps on the track. This problem prevents the automation to operate in a stable way. Fixing the control panel to the chassis with a more flexible structure solves the problem. A manual control system is added when automation system is failed. The vehicle has used in AGROBAY since 2012.

Applying pesticide with autonomous vehicle can protect human health and plants effectively, provide reducing pesticide amount and increase efficiency. The Automation of pesticide spraying has a social – economic effect on the health control of the human beings and plants with watching and controlling the environmental effect.

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APPENDIX

Figure 7.1 Motor picture and specifications

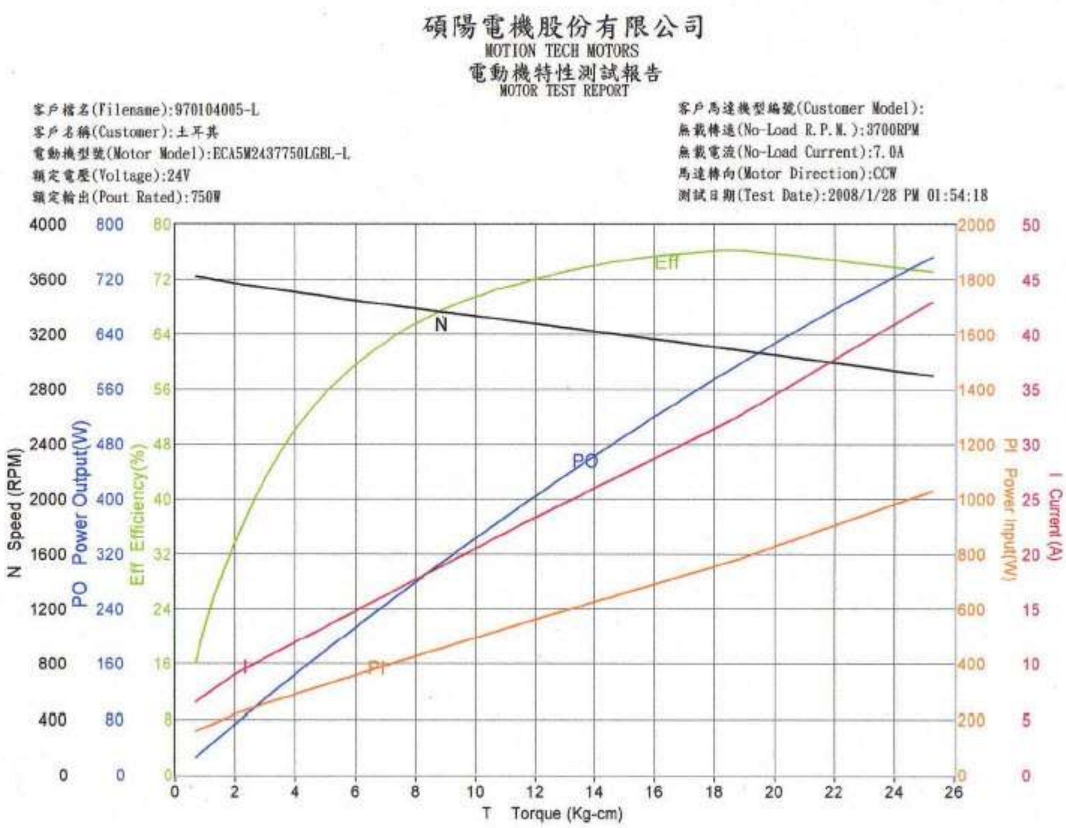

Figure 7.2 Motor test diagram

Pump type	**Tipo de bomba**	**AR DUE**
Type de pompe	**Bomba tipo**	
Pumpentyp	**Pompa tipo**	

TECHNICAL DATA / DONNEES TECHNIQUES / TECHNISCHE ANGABEN
CARACTERISTICAS TÉCNICAS / CARACTERÍSTICAS TÉCNICAS / CARATTERISTICHE TECNICHE

PUMP TYPE TYPE DE POMPE PUMPENTYP TIPO DE BOMBA BOMBA TIPO POMPA TIPO	OUTPUT DEBIT LEISTUNG CAUDAL CAUDAL PORTATA		PRESSURE PRESSION DRUCK PRESION PRESSÃO PRESSIONE		POWER PUISSANCE LEISTUNG POTENCIA POTÈNCIA POTENZA		RPM TOURS/1' U.P.M. REVOLUCIONES/1' RPM N° GIRI/1'	WEIGHT POIDS GEWICHT PESO PESO PESO
	l/min	gpm (US)	bar	psi	HP	kW		kg
AR DUE SP V.R.I.	13	3,4	20	284	0,85	0,62	1400	2,1

5759-AW

Figure 7.3 Pump properties

Specification

Nominal Voltage	12V
Number of cell	6
Design Life	10 years
Nominal Capacity 77°F(25°C)	
20 hour rate(4.0A,10.5V)	80Ah
10 hour rate(7.6A, 10.5V)	76Ah
5 hour rate(13.6A, 10.5V)	68.0Ah
1 hour rate(52.8A, 9.6V)	52.8Ah

Figure 7.4 Battery properties

		l/min																		
		2 bar	3 bar	4 bar	5 bar	6 bar	7 bar	8 bar	9 bar	10 bar	11 bar	12 bar	13 bar	14 bar	15 bar	16 bar	17 bar	18 bar	19 bar	20 bar
TP8001VK	100	0.32	0.39	0.45	0.50	0.55	0.60	0.64	0.68	0.71	0.75	0.78	0.81	0.84	0.87	0.90	0.93	0.96	0.98	1.01
TP80015VK	100	0.48	0.59	0.68	0.76	0.83	0.90	0.96	1.02	1.08	1.13	1.18	1.23	1.27	1.32	1.36	1.40	1.45	1.48	1.52
TP8002VK	50	0.65	0.79	0.91	1.02	1.12	1.21	1.29	1.37	1.44	1.51	1.58	1.64	1.71	1.77	1.82	1.88	1.94	1.99	2.04
XR8003VK	50	0.96	1.18	1.36	1.52	1.67	1.80	1.93	2.04	2.15	2.26	2.36	2.46	2.55	2.64	2.73	2.81	2.89	2.97	3.05
XR8004VK	50	1.29	1.58	1.82	2.04	2.23	2.41	2.58	2.74	2.88	3.03	3.16	3.29	3.41	3.53	3.65	3.76	3.87	3.98	4.08
XR8005VK	50	1.61	1.97	2.27	2.54	2.79	3.01	3.22	3.41	3.60	3.77	3.94	4.10	4.26	4.41	4.55	4.69	4.83	4.96	5.09
XR8006VK	50	1.94	2.37	2.74	3.06	3.35	3.62	3.87	4.10	4.33	4.54	4.74	4.93	5.12	5.30	5.47	5.64	5.81	5.96	6.12
XR8008VK	50	2.58	3.16	3.65	4.08	4.47	4.83	5.16	5.47	5.77	6.05	6.32	6.58	6.83	7.07	7.30	7.52	7.74	7.95	8.16

Note: Always double check your application rates. Tabulations are based on spraying water at 70°F (21°C). See pages 173–187 for useful formulas and information.

Figure 7.5 Teejet flow rate-pressure chart

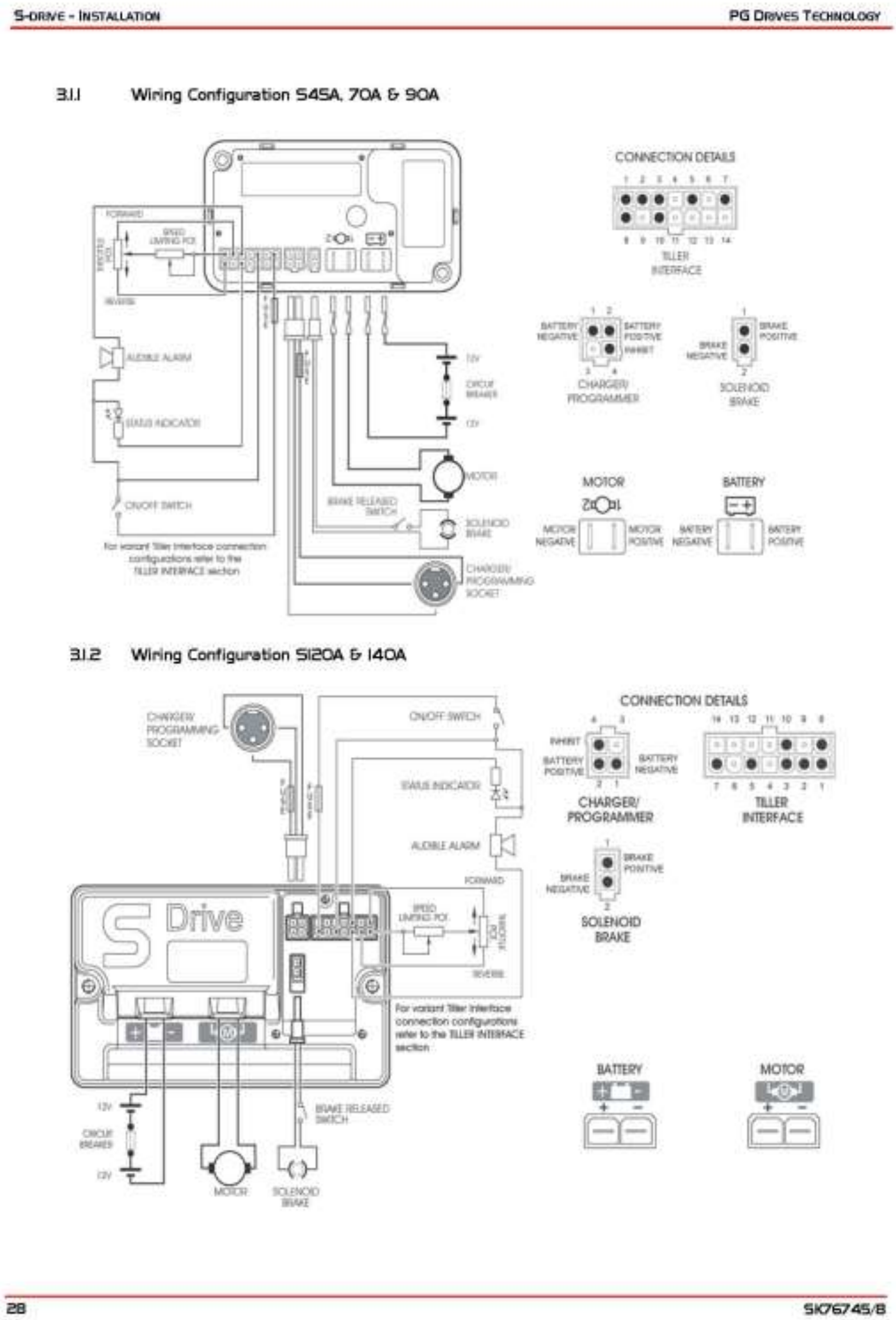

Figure 7.6 Connection Diagram of A Motor Drive

Composition

Element	Weight %
C	0.18-0.23
Mn	0.30-0.60
P	0.04 (max)
S	0.05 (max)

Mechanical Properties

Properties		Conditions	
		T (°C)	Treatment
Density (×1000 kg/m^3)	7.7-8.03	25	
Poisson's Ratio	0.27-0.30	25	
Elastic Modulus (GPa)	190-210	25	
Tensile Strength (Mpa)	394.7	25	annealed at 870°C more
Yield Strength (Mpa)	294.8		
Elongation (%)	36.5		
Reduction in Area (%)	66.0		
Hardness (HB)	111	25	annealed at 870°C more
Impact Strength (J) (*Izod*)	123.4	25	annealed at 870°C more

Thermal Properties

Properties		Conditions	
		T (°C)	Treatment
Thermal Expansion (10^{-6}/°C)	14.8	20-700 more	annealed

Figure 7.7 AISI 1020 Properties