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A Case Study on The Automated Guided Vehicle System Through Reverse Engineering

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***Abstract*—** In This study, AGV System (Automated Guided Vehicle) is considered as the most flexible equipment of MHS (Material Handling System) and one old. In the Indian context, few applications of AGV System have been started in automobile Industry. In this paper, studied the different parts of the AGV, different motions of the AGV driving wheels for carried out various motions, applied reverse engineering technique for developing the 3D CAD model of the existing AGV system, implemented necessary changes in the 3D CAD model for making the AGV suitable for carrying a payload of 50 Kg, analyze the developed model for stress and deflection under the payload, studied the power drive and control system of the existing AGV using Reverse Engineering technique, carried out testing of the different control features of the AGV motions including the sensors, tested the AGV for its basic motions by running test programs in personal computer etc.

***Keywords*—** AGVS, Automated Guided Vehicle, FMS, MHS, Reverse Engineering.

I. INTRODUCTION

Automated Guided Vehicle (AGV) is gaining importance day by day for Material Handling applications in automated factory environment. In develop countries, AGV based Material Handling is implemented in all Flexible Manufacturing System (FMS) installations.

An AGVS (Automated Guided Vehicle System) is a system consisting of an unmanned battery-powered vehicle, a guidance system with other associated components. The vehicle can be programmed to pick up a load at one location and take it to another location automatically. Unlike a conveyor, AGV Systems are actual vehicles that can take materials / products from one location to another following a variety of different paths based on traffic in the area. An AGV path is so programmed that the AGV will move along the path to arrive its final location quickly. Since AGV system is unmanned, it can work 24x7 hours.

The literature survey carried out in the present work reveals that there is a need for research and development on AGV System so that the requirement of the Industry for appropriate automated material handling devices could be made a near future. Therefore, this work had been carried out on the existing AGV system available in the Department.

Keeping this view in mind the present work has the following objectives:

1) To study the different operational functions of an existing AGV System.
2) To study the different motions of the AGV driving wheels for carrying out motions like straight-forward motion, right turn motion, left turn motion, clockwise turn for 180 degree, anticlockwise turn for 180 degree and straight backward motion.
3) To apply reverse engineering technique for developing the 3D CAD model of the existing AGV system.
4) To implement necessary changes in the 3D CAD model for making the AGV suitable for carrying a payload of 50 Kg.
5) To analyse the developed model for stress and deflection under the payload.
6) To study the power drive and control system of the existing AGV using Reverse Engineering technique.
7) To carry out testing of the different control features of the AGV motions including the sensors.
8) To test the AGV for its basic motions by running test programs in personal computer.

Rest of the paper is organized as follows, Section I contains the Introduction with discussion of basic details of the AGV and literature review, Section II contain the research object details specification, Section III contain the Method applied for structural Analysis, Section IV describes Results & Discussion, Section V contain the conclusion, Section VI contains future scope and Section VII contains References.

I.I Literature Review

A lot of work relating to Automated Guided Vehicle (AGV) has been done throughout the previous decades. Out of this some of the most important works are described below:

S. H. Y. Lni and Su-Hna Hsieh [1] presented a procedure to design the AGV travel mechanism. V. R. Milacic and G. D. Putnik [2] proposed the complete structure of an AGV control system and also describe the rules applicable to AGV steering. K. R. S. Kodagoda, W. S. Wijesoma, and E. K. Teoh [3] proposed the development of techniques for lateral and longitudinal control of vehicles and it has become an important and active research topic in the face of emerging markets for AGVs and mobile robots. M. Sharma [4] showed an automated guided vehicle (AGV) was a mobile robot that follows markers or wires in the floor, or uses vision or lasers. G. Klancar, A. Zdesar, S. Blazic and L. Skrjanc [5] presented several applications of autonomous guided vehicles (AGVs) and some emerging fields of research and development in which AGVs are considered. S. Butdee, F. Vignat, A. Suebsomran and P. KDV Yarlagadda [6] proposed a control strategy of Automated Guided Vehicle (AGV). Q. li, A. C. Andriaansen and J.T.Udding [7] studied the design and control of automated guided vehicle (AGV) systems, with the focus on the quayside container transport in an automated container terminal. Dr. G. Arun Kumar and Mr. J. Paul J. Thadhani [8] presented a paper and in it they stated that Automated Guided vehicle (AGV) is like a robot that can deliver the materials from the supply area to the technician automatically. Kim et al. [9] proposed a deadlock detection and prevention algorithms for AGVs. Wuwei et al [10] presented the new navigation method for AGV with fuzzy neural network controller when in the presence of obstacles. Alves and Junior [11] used a step motor to turn the direction of the ultra -sonic sensors, so that each sensor can substitute two or more sensors in mobile robot navigation. P. S. N. Priyanka, J.S.S. Rositha, K. SriNavya and N. Priyanka [12] developed DTMF based Automation controlled by Mobile Signals.

I.II Complete Set of an AGV System:

A complete set of an AGV system is shown in Figure 1.

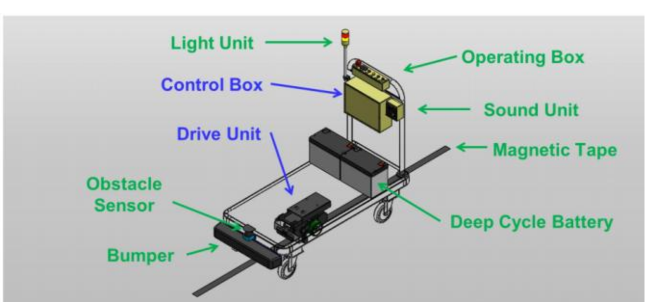


Figure 1: Complete set of an AGV System

The accessories of complete set have been shown in Figure 2:

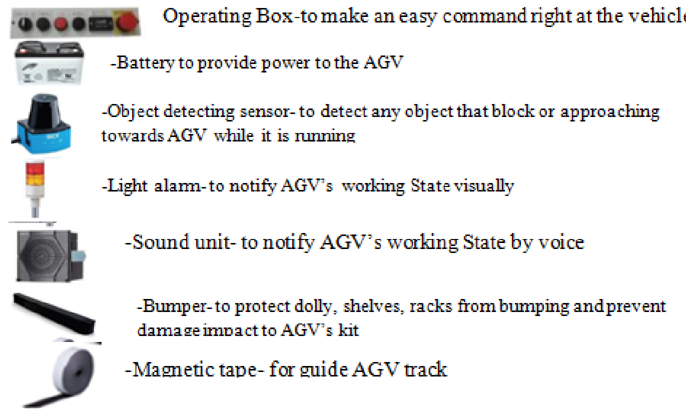


Figure 2: the Accessories of complete set

I.III AGV System Classification:

In this section, AGV System classification has been shown in Figure 3:

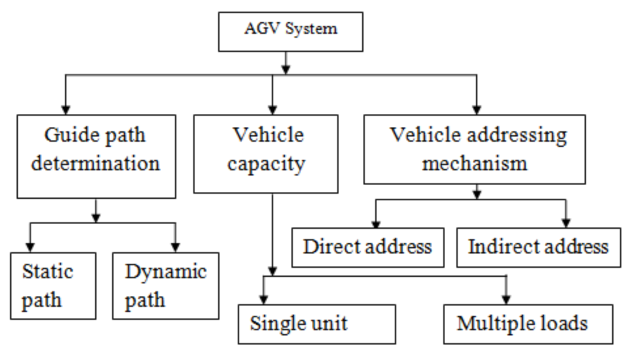


Figure 3: AGV System Classification

I.IV AGV System Components:

AGVS use many different components to assist it in getting a load from one point to another. The various components of the AGV System are listed below:

I.IV.I Mechanical Components:

The Mechanical components in an AGV System are -

a. Chassis or Main body
b. Steering system
c. Lift mechanism
d. Driver gears
e. Pinion gears
f. Belts

I.IV.II Electrical Components:

Electrical components include the motor and the power supply unit for motors.

a. Motor,
b. Battery

I.IV.III Electronics Components:

The various Electronics Component of an AGV System are listed as below:

a. Controller
b. Motor driver kit
c. Main kit
d. Intermediate Kit
e. Modem
f. Sensors/ Obstacle Detector

I.V Types of AGV System:

Various types of AGV System are:

i. Towing Vehicles AGVS
ii. Unit Load AGVS
iii. Pallet Trucks AGVS
iv. Forklift Trucks AGVS
v. Light-load AGVS
vi. Assembly line AGVS

I.VI Various type of guidance systems [13] are:

i. Wire Guidance System
ii. Laser Guidance System
iii. Spot Guidance System
iv. Paint/Chemical Guidance System
v. Dead Reckoning Guidance System
vi. Beacon Guidance System
vii. Inertial Guidance System or gyro navigation

II. RESEARCH OBJECT DETAILS

The details views of the existing AGV system in the FMS Lab are shown in Figure 4, Figure 5 and Figure 6:

Figure 4: Bottom view

Figure 5: Top view

Figure 6: Front view

The various parts of this AGV System are: Battery Box, Motor (24V), Timing Belt, Control Box, Swivel Custer, Docking Pins, Power Drive System, Wheels, Toothed Wheel attached with motor Shaft, Reset Switch, Motor power and Battery power Switch.

II.I REVERSE ENGINEERING:

At a higher level, there are two types of engineering: Forward engineering and Reverse engineering.

Forward engineering is the traditional process of moving from high-level abstractions and logical designs to the physical implementation of a system. In some situations, there may be a physical part without any technical details, such as drawings, bill-of-material, or with engineering data, such as thermal and electrical properties.

The process of duplicating an existing component, subassembly or product without the aid of drawing, documentation or computer model is known as Reverse Engineering.

II.II Model in INVENTOR Software:

In the current research work Autodesk Inventor 2016 has been used to create the 3D models of different parts of the AGVS and to prepare 2D drawing of those parts. Stress analysis of the AGVS has been also done by Autodesk Inventor 2016.

The modelled Mechanically Assemble view and different parts view of the AGV system are shown below from Figure 7 to Figure 25:

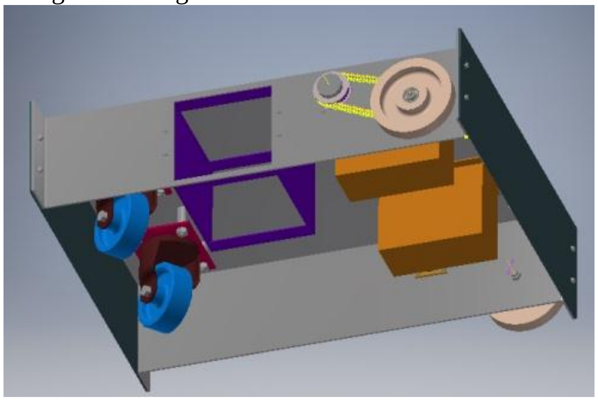


Figure 7: Assembled view of the existing AGV system

II.I.I Main Body:

Material: Mild Steel

Figure 8 and Figure 9 shows the 3D and details diagram of the Main Body.

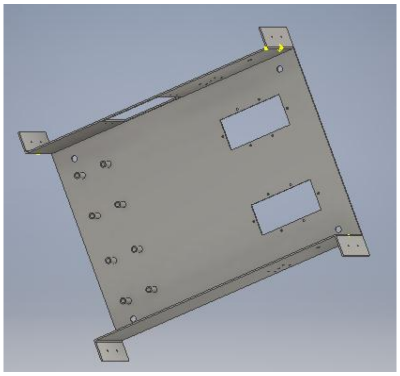


Figure 8: 3D view in Inventor

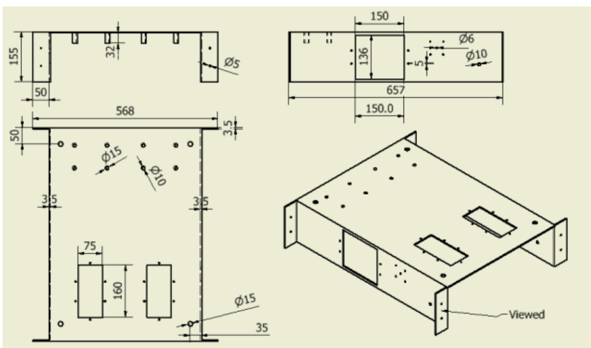


Figure 9: Details Diagram

II.I.II Front and End cover:

Material: Aluminium

Figure 10 and Figure 11 shows the 3D and details diagram of the Front and End cover.

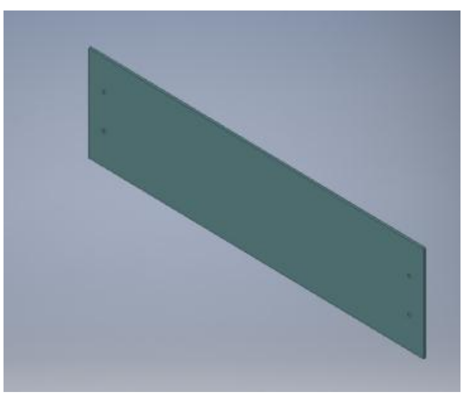


Figure 10: Front and End cover

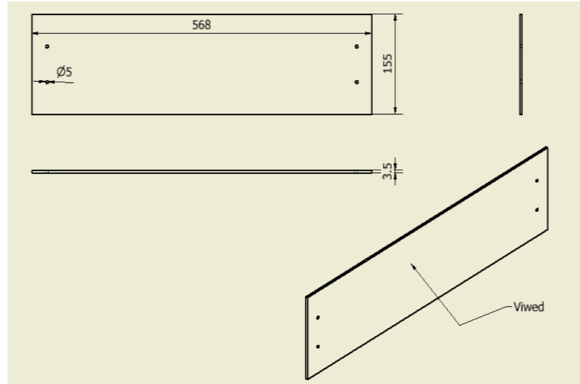
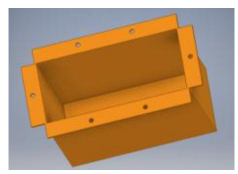


Figure 11: Front and End cover Details drawing

II.I.III Battery Container Box:

Material: Aluminium

Figure 12 and Figure 13 shows the 3D and details diagram of the Battery Container. The specification of the battery is given in Table 1.



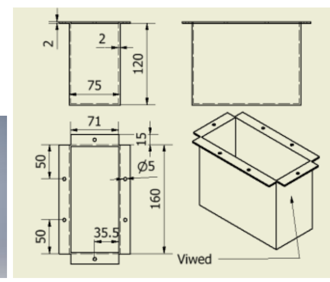


Figure 12: 3D view *Figure 13: Details Diagram*

Table 1: Specification of the Battery

Manufacturer	Exide Industries Ltd.
Battery Model	CS 7-12
Type	Lead acid battery
Battery Voltage (V)	12
Capacity	7Ah
Dimensions(mm)	151x100x65
Weight	2.6 kg
Metal of Battery container	Aluminium
No. of Battery	2

II.I.IV Timing Belt:

Material: Rubber

Figure 14 to Figure 16 shows the 3D and details diagram of the timing belt. No. of timing Belt: 2

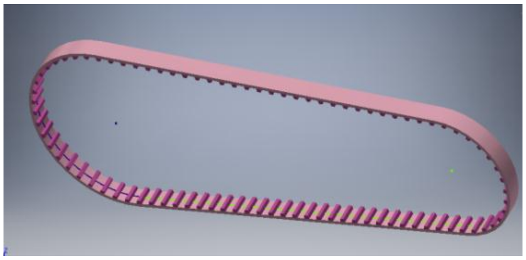


Figure 14: 3D view in Inventor

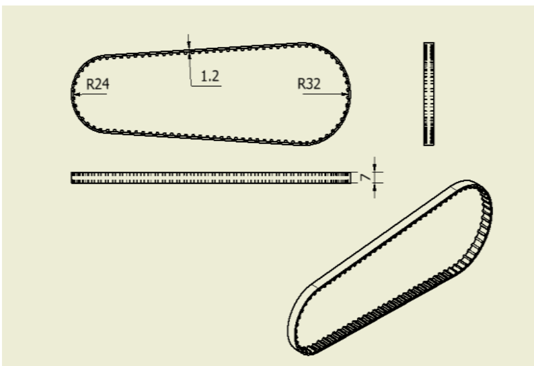


Figure 15: Details Diagram

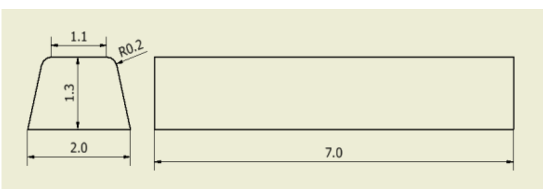


Figure 16: Tooth Details

II.I.V Wheel arrangement (Axle Axis):

Hub material: Mild Steel,
Gear material: Nylon,
Wheel Material: Rubber
No. of wheel arrangement: 2

Figure 17 and Figure 18 shows the 3D and details diagram of the wheel attached with axle axis.

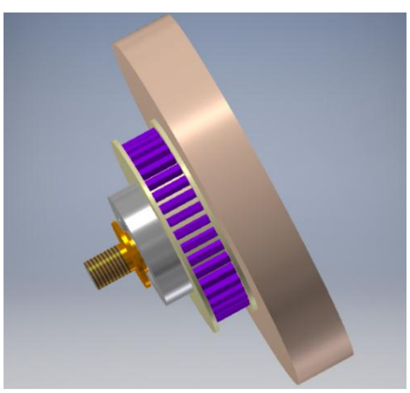


Figure 17: 3D view in Inventor

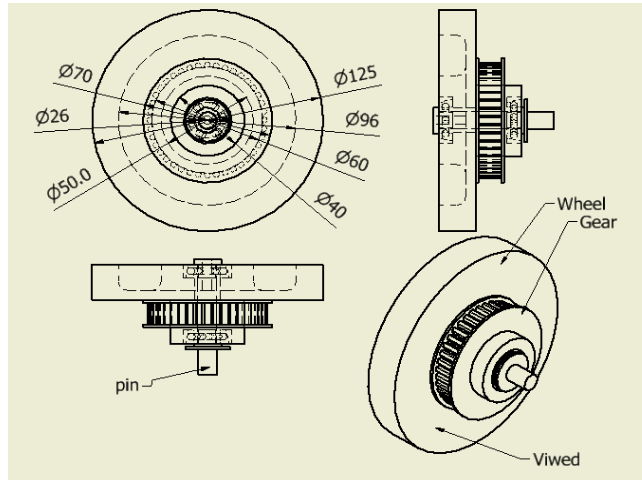


Figure 18: Details Diagram

II.I.VI Toothed Motor shaft wheel:

Hub material: Mild Steel,
Gear material: Nylon,
Wheel Material: Rubber
No. of wheel arrangement: 2

Figure 19 and Figure 20 shows the 3D and details diagram of the wheel connected to the motor shaft.

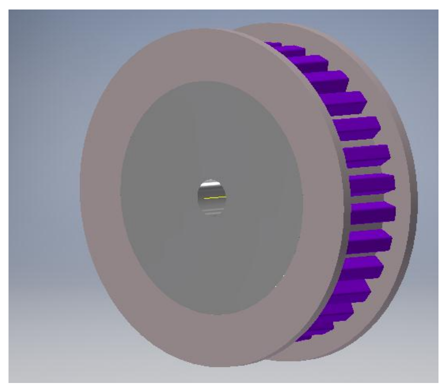


Figure 19: 3D view in Inventor

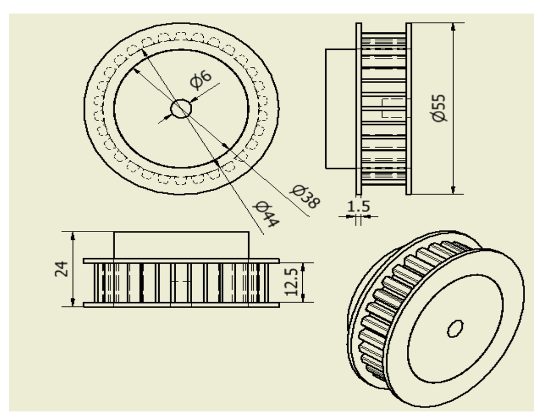


Figure 20: Details Diagram

II.I.VII Details of the swivel Custer wheel:

Figure 21 and Figure 22 shows the 3D and details diagram of the swivel Custer wheel. No. of wheel arrangement: 2

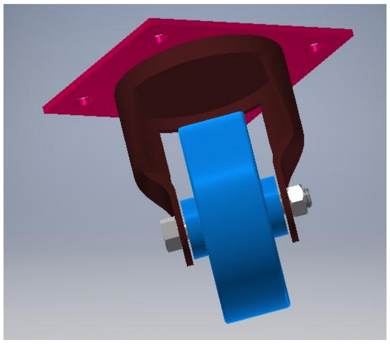


Figure 21: 3D view in Inventor

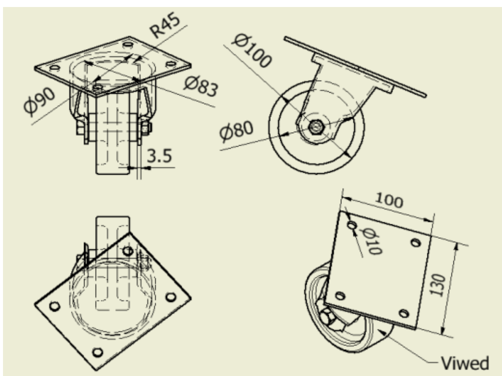


Figure 22: Details Diagram of the Custer wheel

II.I.VIII Bearing:

No of bearing: 2
Dimensions: Outer Diameter: 26mm,
Thickness: 8mm
Family: PN-87/M-86160 (from Autodesk Inventor Library)

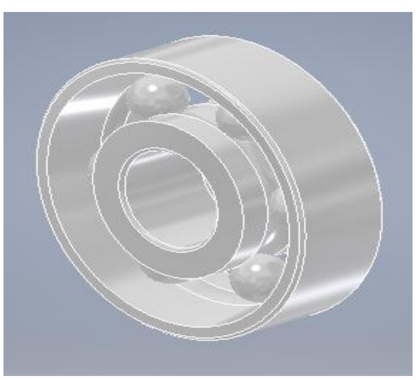


Figure 23: Bearing

II.I.IX Motor:

Figure 24 and Figure 25 shows the 3D and details diagram of the Motor. No. of Motor: 2

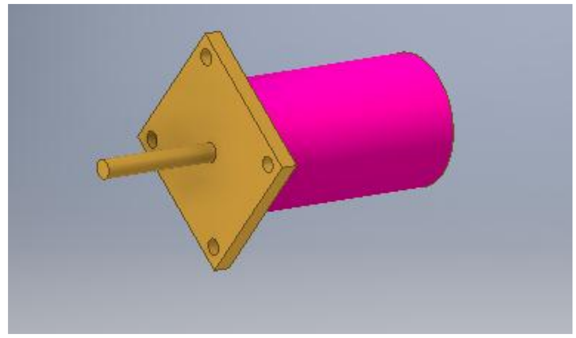


Figure 24: 3D view in Inventor

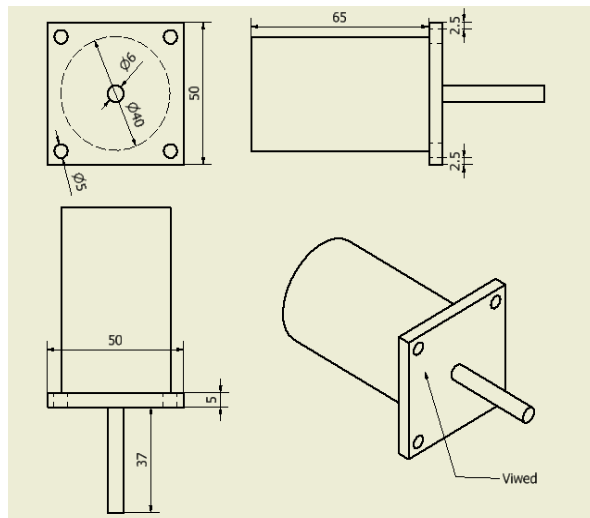


Figure 25: Details Diagram

Two motors have been considered for this system. Axis of the motor is perpendicular to the side face of main body. The motors are fixed with the side face of main body using screw. The specifications of the motor are given in Table 2.

Table 2: Specification of the Motor

Manufacturer	Maxon DC motor
Manufacturer Part No	2140.937-61.112-050
Type of motor	Stepper Motor
Quantity	2pc
Nominal Voltage	24V
No Load Speed	4110rpm
No Load Current	6019A
Nominal Speed	2420rpm
Nominal torque of motor (max. continuous torque)	13.6 mN m
Nominal current (max. Continuous current)	0.164A
Motor Outer Dimension with gearbox	Ø 40mm x65mm
Spindle dimension	Ø6mm x37mm
Weight	190gm
Maximum torque after gearbox	0.1-0.6 Nm
Change gear ratio	17:75

III. METHODS

In this study, Reverse engineering process has been carried. Dimensions of the various parts of the object noted and model a 3D duplicate replica using those dimensions in 3D Modelling Software Autodesk Inventor, 2016. The material of the each object has been specified and find out the C.G. of the whole system. It's also assigned the various constraints on the system. Applied the gravity and 50 kg pay load on upper face of the body. Required torque and power also calculated for 50 kg payload with mass of the system in addition 20% mass allowance.

Stress simulation and analysis process was done in inventor 2016 on the main body of the AGV system. Consider the metal of the main body is Mild Steel. Measured the all dimensions of the AGV and a 3D model in assembly view was developed using Autodesk Inventor software. The C. G. point and the mass of the whole system were measured using Autodesk Inventor.

The reference axis of the modelled part is shown in Figure 26.

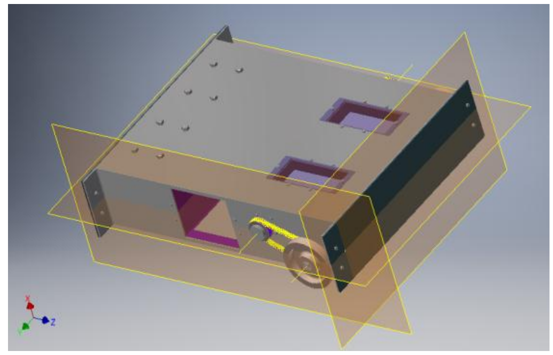


Figure 26: Reference axis for analysis of the Model

To simulate and stress analysis in Autodesk Inventor, there are several steps. After open the body in Inventor, go to "Environment" and then "Stress Analysis" option to create the Simulation page. A photocopy of that page is listed in Figure 27. After creating simulation page, assign the material of the body, give constrains, apply load and simulate.

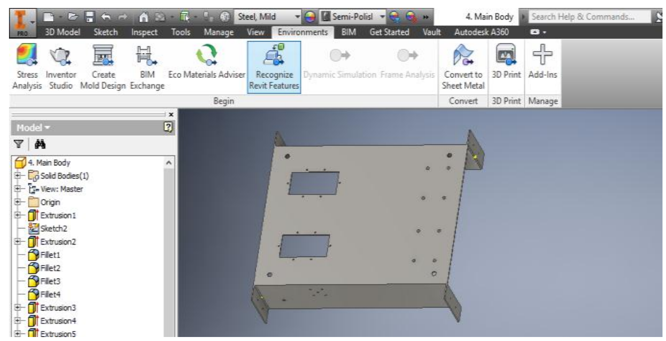


Figure 27: Initial steps to create simulation page in Inventor

In this case, consider mild Steel as a metal of the body. The assign constraints for simulation are shown in Figure 28, Figure 29, Figure 30 and Figure 31

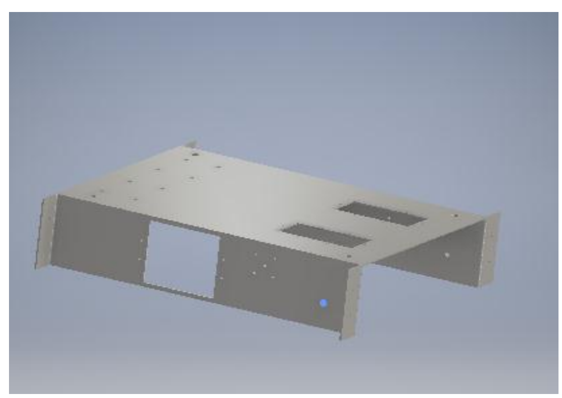


Figure 27: pin Constraint: 1

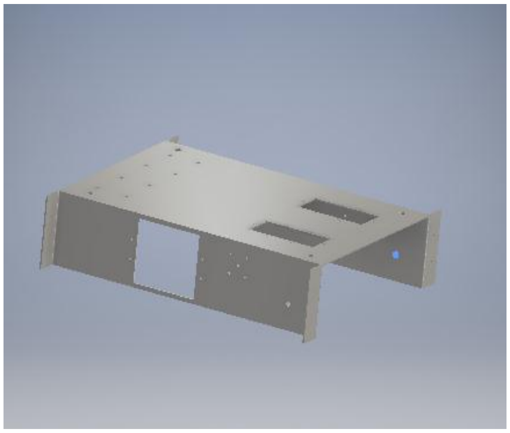


Figure 29: pin Constraint: 2

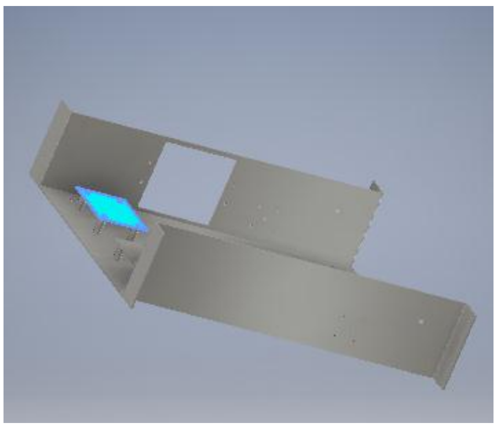


Figure 30: Fixed Constraint: 1

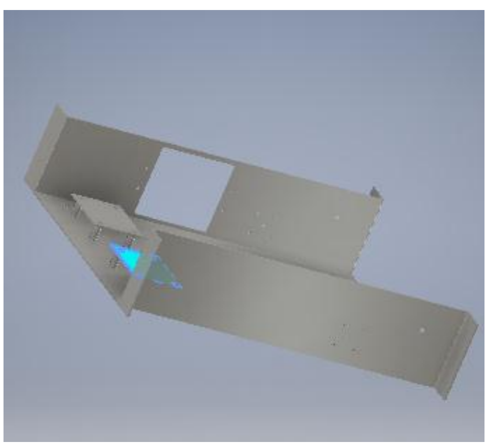


Figure 31: Fixed Constraints: 2

The total weight of the AGV System (measured by Inventor)
$= 31$ Kg
Taken 20% extra weight, then total weight$=31\times 1.2$
$=37.2$ Kg
The weight of the main body$=13.5$ Kg
So, total weight of AGV excluding main body
$=37.2-13.5=23.7$Kg

Since, the weight of the main body is distributed throughout the area uniformly and symmetrically, so Main body weight did not taken into account to calculate the CG of the system.

The measured Centre of Gravity point with respect to the reference axis (Figure 32) $= (22, -220, -306)$

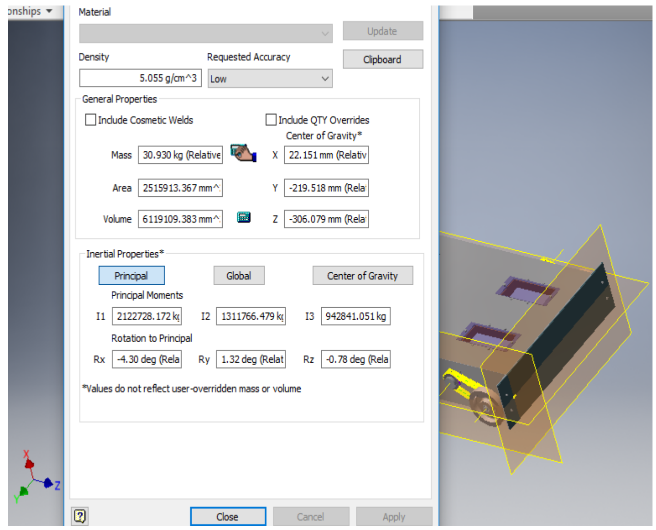


Figure 32: C.G. of the AGV System

Now, the gravity load is applied on the main body as shown in Figure 33 to analyze this part.

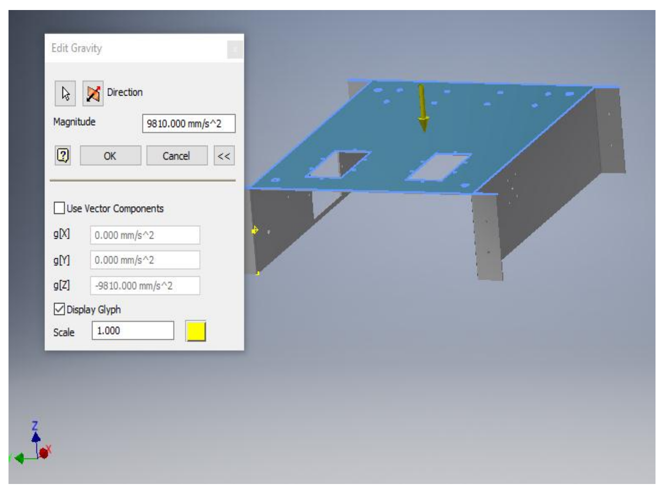


Figure 33: Gravity Load

Followed that step, applied 50Kg as a pay load in CG point of the upper face where pay load is applying and 23.7 Kg as a total weight of AGV excluding main body in CG point as shown in Figure 36 and Figure 37.

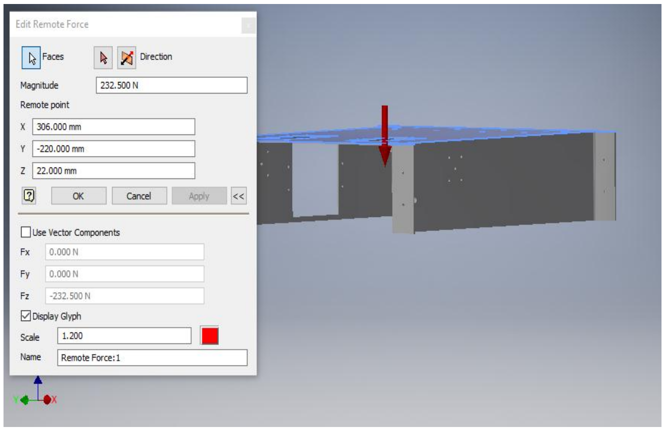


Figure 36: Applied load in CG

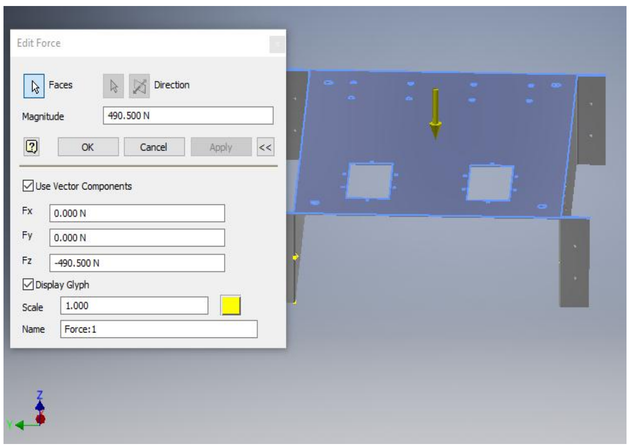


Figure 37: Payload applied in upper face of the body

IV. CALCULATION AND RESULTS

IV.I Torque and Power Calculation for Motor:

Consider, required time for the vehicle to reach a speed ($v \approx 10$ m/min), t= 1sec

So, angular speed of the housing wheel, ω_1=24 rpm

$$= \frac{2\times\pi\times 24}{60} = 2.51 \text{ rad/sec}$$

So, linear velocity,

$$v= \frac{\pi\times D\times N}{60} = \frac{\pi\times 125\times 24}{60} = 9.42 \text{ m/min}$$

Angular speed of pinion,

$$\omega_2= \frac{\omega_1\times T_1}{T_2} = \frac{2.51\times 40}{30} = 3.35 \text{ rad/sec}$$

(Diameter of the housing wheel=125mm)

Consider, Co-efficient of friction, μ= 0.3

Limiting Frictional Forces:

For 500N load, from analysis in Autodesk Inventor 2016, Reaction forces in Housing wheels are 214N and 200N. So, designing reaction force, N=214 N

So, limiting Frictional Force

$F` = \mu\times N = 0.3\times 214 = 64.2N$

Acceleration of the body,

$a = v \div t = 0.157 \div 1 = 0.157$ m/sec^2

Consider extra 20% mass of the system.

So, Total mass of the body with 20% extra= 37.2 Kg

Pay load=50Kg acts on mass Centre of Gravity of the load.

So, Inertia Force $F_1 = m_1 \times a = 37.2\times 0.157 \div 5.84N$

and $F_2 = m_2 \div a = 50\times 0.157 = 7.85N$

Now, Inertia force on wheel on one wheel,

$F_B = [(F_1\times 264) + (F_2\times 278)] \div 556 = 6.69N$

And inertia force on another wheel,

$F_A = F_1 + F_2 - F_B = 7N$

So, maximum inertia force on the wheel < Frictional force

(7< 64.2)

So torque in wheel=torque in large toothed wheel,

=64.2× (125÷2) N mm =4.01 N m

Power in motor wheel= Torque in motor toothed wheel × Angular speed of motor toothed wheel= 4.01× 2.51

=10.07 W

So, power of motor =10 W

And torque of the motor =10÷3.35=2.99 N m

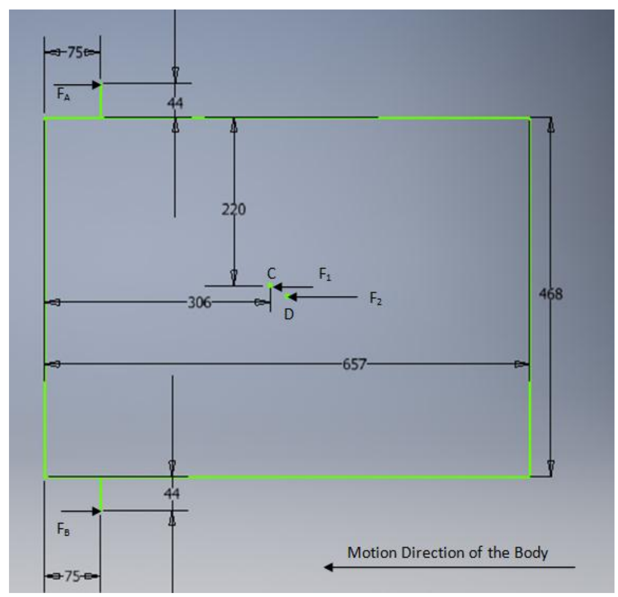


Figure 38: 2-D kinematic System of the AGV

IV.II Stress Analysis Results:

The results table after simulation of the main body in Inventor is shown in Table 3 where the various data of Reaction forces and Moments on Various Constraints are recorded (Magnitude as well as various components values).

Table 3: Reaction Force and Moment on Various Constraints

Constraint Name	Reaction Forces		Reaction Moments	
	Magnitude (N)	Component (X,Y,Z) (N)	Magnitude (N m)	Component (X,Y,Z) (N m)
Fixed Constraints:1	288.952 N	-186.335	4.46954 N m	-0.549517
		4.61383		4.43453
		220.797		0.0986607
Fixed Constraints:2	243.167 N	-82.2572	9.30721 N m	-0.145654
		-4.64439		8.19079
		228.785		4.41745
Pin Constraints:1	271.862 N	167.329	7.46965 N m	-7.45132
		0		0
		214.266		-0.52298
Pin Constraints:2	224.44 N	101.286	7.29879 N m	7.28783
		0		0
		200.286		0.399875

The Maximum and Minimum stress on the main body using Von Misses Criteria is shown in Figure 39.

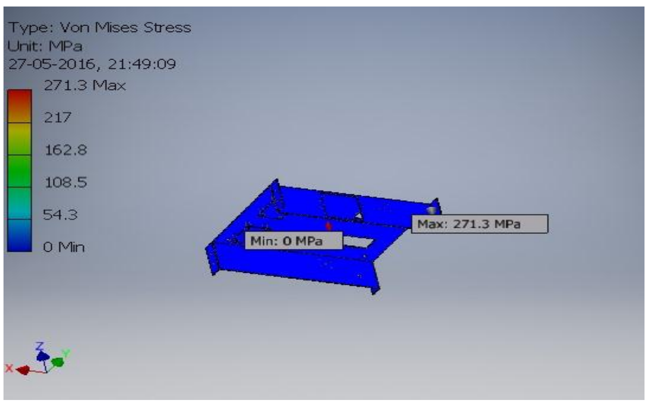


Figure 39: Maximum and Minimum Stress using Von Misses Criteria

IV.III Displacement Analysis Results:

The maximum and minimum displacement of the main body after analyze in Inventor is shown in Figure 40.

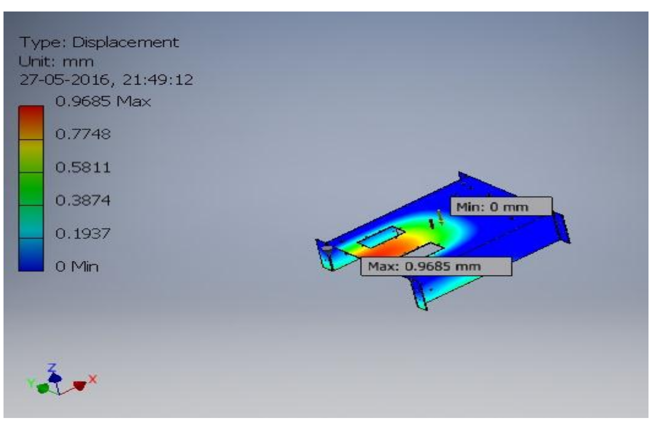


Figure 40: Maximum and Minimum displacement

V. CONCLUSIONS

In the present work Reverse Engineering approach has been followed for bringing an existing AGV System into operation, which was lying for a long time out of operation. Starting from creation of the basic 3D model of the existing AGV System, understanding the operational control action of the control unit and finally testing the AGV for some simple operations through sending appropriate signals to the Relay Board – all these activities have been performed successfully.

In view of the present work on the study of an AGV System through Reverse Engineering following conclusions may be drawn:

1. 3D CAD model of the existing AGV System has been developed through Reverse Engineering.
2. 2D CAD drawings of the different parts of the existing AGV System have been prepared.
3. Control actions for wheel motions forward/reverse at higher/lower speeds have been identified and understood.
4. The control pin no.'s that are responsible for control action as mentioned in 3 above have been identified.
5. The control pin no.'s that are responsible for sending signals from the track sensors and the junction sensor have been identified.
6. Testing for wheel motions as stated in 3 above have been performed successfully by applying suitable control voltages to the respective pin no.'s.
7. Testing for generating sensor signals as stated in 5 above have been performed successfully by measuring sensor output voltages while bringing metal substance in the proximity of the sensors.
8. Testing the AGV for its turning motion (right and left) has been performed successfully.
9. From Stress analysis, it has been observed that the main body frame can withstand 50 kg payload without any danger. But deflection analysis reveals that maximum 0.9685 mm deflection may occur due to pay load which is also under safe condition.

The work carried out in the present investigation has helped to bring the unused AGV system into operation.

VI. FUTURE SCOPE

The existing AGV system has been studied in details and many control information have been collected. This information's may be utilized in near future for running the AGV with all its features with the help of a personal computer. There is also a need to interact with the existing microcontroller for proper control action and guidance for the AGV system. It may also happen such that the controller with its operational program may not be accessible. In such situation a new microcontroller may be considered and the program transfer from the personal computer has to be wireless.

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