Design of Automatic Vertical Storage System for Printing Rolls

By

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Design of Automatic Vertical Storage System for Printing Rolls

Major Project Report

Submitted in partial fulfillment of the requirements

For the Degree of

Master of Technology in Mechanical Engineering (Computer Intergreted Manufacturing)

By

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Guided By

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MAY 2017

Declaration

This is to certify that

1. The thesis comprises my original work towards the degree of Master of Technology in Computer Integrated Manufacturing at Nirma University and has not been submitted elsewhere for a degree or diploma.

2. Due acknowledgement has been made in the text to all other material used.

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I, **Nishant Vyas**, Roll. No. **15MMCM08**, give undertaking that the Major Project entitled "**Design of Automatic Vertical Storage System for Printing Rolls**" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Mechanical Engineering (Computer Intergreted Manufacturing)** of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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This is to certify that the Major Project Report entitled "**Design of Automatic Vertical Storage System for Printing Rolls**" submitted by **Mr. Nishant Vyas (15MMCM08)**, towards the partial fulfillment of the requirements for the award of Degree of **Master of Technology in Mechanical Engineering (Computer Intergreted Manufacturing)** of Institute of Technology, Nirma University, Ahmadabad is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination.The result embodied in this major project, to the best of our knowledge, has not been submitted to any other University or Institution for award of any degree.

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Abstract

Increase in range of products has created need and importance of the scientific vertical storage systems. Factors like reduction in inventory, mass production, easy storage/retrieval and workers' safety shows the necessity of storage systems. Because of its high storage/retrieval capacity popularity and importance of vertical storage system is increasing in the industries. Vertical storage are essential for companies as constant performance and accuracy in terms of picking of orders is required.

In printing industry, wide ranges of rolls are being stored on vertical racks or floor when they are not in use which occupies the floor space and causes stock inaccuracies. Thus, in order to solve the storage problem as well as to utilize the vertical space, automatic vertical storage system is preferable to use.

The aims of this project are to design the automatic vertical storage system for printing rolls which utilizes the vertical space in the industry, obtain better inventory control , ensure safety of the workers and in turns reduces the loading and unloading time. In the present study, a conceptual design of carousel has been done using Solid Edge ST9 software. Analytical calculations and FEA simulation of the critical parts have been carried out by using ANSYS software. Validation of the design also carried out by using ANSYS software.

Keywords : *Verticalstorage*, *ASRS*, *Design*, *Chaindrive*, *FEAsimulation*

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Nomenclature

F, C_p	Chain pull/Maximum load (N)
T	Torque (Nm)
r	Radius (m)
d	Diameter (m)
P	Power (kW)
σ_1	Maximum principle stress (N/mm^2)
M_b	Bending moment (Nmm)
M_t	Torsional moment (Nmm)
σ_{yt}	Yield strength (N/mm^2)

Abbreviations

AS/RS	Automatic Storage and Retrieval System
I/O	Input/Output
IRR	Independent Rotating Rack
FOI	Factor Of Inquiry
PH	Product Height
SSU	Storage Space Usage
PD	Path to Dispatch
S/R	Storage/Retrieval
SBS/RS	Shuttle-Based Storage and Retrieval System
CSP	Class-based Storage Policy
ACO	Ant Colony Optimization
MPC	Model Predictive Control
MLD	Mixed Logical Dynamical
FEA	Finite Element Analysis
MS	Mild Steel
PCD	Pitch Circle Diameter
RPM	Revolutions Per Minute

Chapter 1

Introduction

1.1 Overview of Automatic Storage and Retrieval System (AS/RS)

Automatic vertical storage system is one type of AS/RS. AS/RS is composed of variety of systems controlled by computers for automatic load placements and retrieval of loads from preset storage locations. AS/RS are generally used where very high volume of load or product is being moved in and out of storage.

The main elements of an AS/RS are cranes, input/output points, racks, aisles and pick up positions. Cranes are automated machines which can move autonomously while picking up or dropping off loads. Location where loads are picked up or dropped off can be called as Input/Output points. Racks are metal structures, providing location for storage of loads. Empty spaces between racks, for movement of cranes can be called as Aisles. Pick positions are places where an individual item can be removed from already retrieved load before load is sent back to the system. . Figure 1.1 displays various components of AS/RS systems.

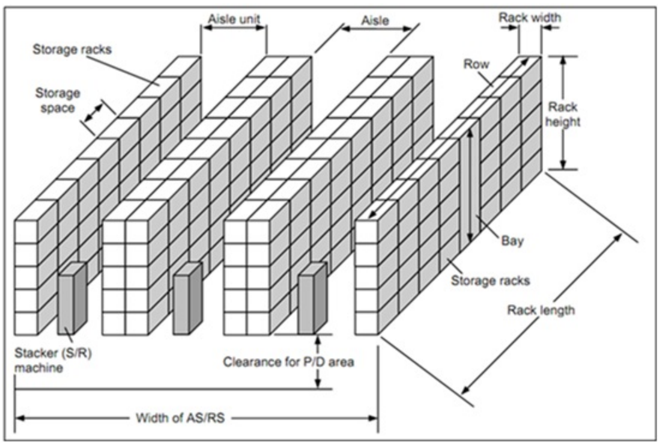


Figure 1.1: Components of AS/RS

Important variables for such systems are columns, number of bins, service time, rows and operator utilization. Popularity of horizontal as well as vertical storage systems is increasing due to their easy material handling, storage capacity, easy computer control adaption by industry and complete automation.

The bins move in horizontal plane for horizontal storage system, where as bins move in vertical plane for vertical storage systems. Utilization vertical space and minimization of floor space occupied is the main concept of vertical storage system/vertical carousel. It also reduces effort for the workers as load is delivered at desired location or height.

1.1.1 Advantages of AS/RS

1. High stock keeping capacity within limited space
2. Provides protection from damage for storage goods
3. Automation of storage and retrieval process
4. Reduced Labor
5. Increased accuracy as human intervention is minimum

1.1.2 Disadvantages of AS/RS

1. Unpredictable/excessive development costs
2. Any automated system has its limit to level of intelligence and hence possibility of errors.

1.2 Types Of Storage Systems/Carousels

1. Horizontal Storage System/Carousels
2. Vertical Storage System/Carousels
3. Independent Rack Storage System/carousels

1.2.1 Horizontal Storage System/Carousel

In Horizontal Storage Systems movement of bins is in horizontal plane, as it delivers the items. In horizontal storage system bins are driven in horizontal plane by motor. This increases rate of order picking compared to traditional method. It also increases speed of stock retrieval and saves space. Figure 1.2 displays an example of Horizontal storage system.

Figure 1.2: Horizontal storage system

It has comparatively low maintenance and durability. It provides safety, better and faster order picking, good inventory control and saves space.

Rotational speed can be about 25metres/min. While horizontal length can vary from 4 meter to 30 meter and height from 1.5 meter to 8 meter.

Bins are further divided into several adjustable shelves which permits different capacity in each bin.

Hence possibility of more storage capacity in horizontal storage system compared to vertical storage system, as frames of ladder support horizontal storage which are within centre of loop.

1.2.2 Vertical Storage System/Carousel

Vertical storage system consists of rotating shelves that move in vertical direction, and delivers items as per our convenience. Vertical storage system increases efficiency and storage capacity and also reduces inventory and labor costs. The main objective is to free floor space for other work while utilizing vertical space. Parts are delivered at desired height according to convenience of workers. . Figure 1.3 shows an example of vertical storage system.

Vertical storage system scan be manually operated or fully automated. It has same working principle of rotation of shelves, as of horizontal storage system. Guided from both ends, shelves move in vertical series.

Figure 1.3: Vertical storage system

In vertical storage system, operator gets the delivery of material at desired height which increases safety and saves time as lifting or bending for heavy objects is minimized. vertical height can be up to 10 meter in air. storage is supported by structure and metal case encloses the whole structure.

1.2.3 Independent Rotating Rack (IRR) Storage system

Independent Rack storage system consists of many single leveled horizontal storage systems which provides access to multiple pick locations at any time to the order picker. Each level of IRR storage system works independently and has its own communication link and power source. Hence, many locations of storage are available for the operator all the times Most common application for IRR storage is remote order picking. A robot is kept at one end for storage and retrieval of items, in such applications. Hence high efficiency and storage capacity can be obtained for Independent Rotating Rack. Figure 1.4 shows an illustration of Independent Rotating Rack Storage system. As discussed above each level works independently, hence requires its own independent power source thus increasing overall cost of IRR storage system compared to vertical or horizontal storage systems.

Figure 1.4: Independent Rotating Rack Storage system

1.3 Objectives

1. To design an automatic vertical storage system for printing rolls.
2. To analyze and validate the design of critical components of the vertical storage system under static loading condition.

1.4 Outline of the Report

Outline of the report is as follows :-

Chapter 1: Introduction
Chapter 2: Literature review
Chapter 3: Conceptual Design of Automatic Vertical Storage System
Chapter 4: FEA Simulation
Chapter 5: Conclusion and future scope

Chapter 2

Literature Survey

1. Kees Jan Roodbergen and Iris F.A. Vis [1] has given an overview of literature explaining the current scenario on AS/RS design. Topics like dwell point location, storage assignment, travel time estimation, sequencing request, and measurement of performance of the system are covered. Control and design problems in static environment are addressed. That is focus on one or two decision problem and not on multi decision problem where AS/RS is combined with other material handling systems.

2. David T. Buley and Kenneth Knott[2]developed an algorithm for obtaining the solution regarding design and selecting of the independent racks for vertical storage system. Above problem can be solved by reducing number of independent columns and increasing utility of order pickers. Specification of bin, type and number of single material can be stored in bin should be know. The size of bin should be constant throughout the system.

3. Latéfa Ghomri and Zaki Sari[3]focused on proposing mathematical model for travel time for flow-rack AS/RS. The model proposed in paper is function of physical parameters of system such as length, width & depth and also function of variety of products stored in the system and of their proportion. Validation of mathematical model was also done through simulation in arena/siman simulation software.

4. Henri Tokola and Esko Niemi[4]studied detailed slotting in mini load AS/RS. A detailed slotting rule based on best fit rule is constructed and analyzed in the paper, which aligns cartons next to the longer carton on both ends. Compared to first fit rule without aligning, simulation results show as much as 10% saving in the utilization. Benefit of 1% is obtained by aligning carton next to longer carton instead of next to shorter carton.

5. I. A. Daniyan et al.[5]discussed design calculations regarding belt conveyor system used for transfer of limestones using 3 rolls idlers. Calculations regarding design were

done in terms of speed, power, tension, roller diameter, size, capacity, length and idler spacing. Calculations in terms of type of drive unit, diameter, location and arrangement of pulley, angle and axis of rotation for fast, continous and efficient movement of limestone was also done, such that fatalities can be avoided while loading and unloading.

6. Raghvendra Singh gurjar et al.[6]studied factors tending to failure of belt conveyor system in termal power plant. Paper also shows maintenance of belt conveyor system in coal handling system. Technical characteristics which prevents failure of belt conveyor has been analyzed in paper. For the prevention and elimination of failure, maintenance method is done.

7. Simon Brezovnik et al.[7]showed planning of AS/RS by using multiple objective Ant Colony Optimization (ACO).The products in AS/RS are distributed based on Product Height (PH), Path of Dispatch (PD), Factor Of Inquiry and Storage Space Usage. Simulation results show that ACO can be successfully plan automated storage system.

8. Jörg Oser and Christian Landschützer[8]focused on analytical and dynamic solutions for problems like drive location during design of drive systems in material handling equipments. To solve the drive location problem, an analytical solution was presented. In order to avoid expensive iteration steps at later design stages, a refined simulation model was developed. Simulation model was developed to extend the static model with dynamic effects. Dynamic models for the systems were made in MATLAB and ITI-sim.

9. Ya-Hong Hua et al.[9]presented S/R mechanism that allows AS/RS to handle very heavy load efficiently. High lifting capacity, more flexible AS/RS rack conFigureuration and high fault tolerance are some of advantages of Sp-AS/RS. A continuous travel time model was presented for new AS/RS under stay dwell point policy. Validation of model was done by computer simulations.

10. B.Y. Ekren et al.[10]aimed to perceive the best rack design for shuttle based storage and retrieval system (SBS/RS). For high transaction environments where mini load AS/RS cranes are not able to keep up with pace of transaction rate needed, a new technology in AS/RS was developed namely SBS/RS. Parameters like utilization of lifts, storage retrieval devices and cycle times of S/R transactions were used to evaluate performance of the system.

11. Shie-Gheun Koh et al.[11]studied a horse-shoe type end-of-aisle order picking system in a mini load AS/RS. The order picking system was modeled as a closed queuing network, which has a limited queue length. Model was analyzed with supplementary

variable technique to find the long run behavior of the system. Paper proposed a simple optimization model and presented results of some similar problems.

12. Young Hae Lee et al.[12]proposed a model of AS/RS containing rack of modular cells that can hold various size of unit load. Storage volume for each load type was considered while developing a mathematical model of cell size. Model developed has more flexibility to size and has higher space utilization as compared to existing rack structure.

13. Konakalla Naga Sri Ananth et al.[13]provided with design of conveyor system which included calculations for belt width, motor selection, gearbox selection, belt specification, belt speed, shaft diameter, pulley and shaft diameter.

14. Danielle J. Nativ et al.[14]used Mixed Logical Dynamical (MLD) for Model Predictive Control (MPC) of an AS/RS. The non linear dynamic model equations and constraints of AS/RS were transformed into MLD form using propositional calculus.

Chapter 3

Conceptual Design of Vertical Storage System

Vertical storage system consists of bins or gripper type of arrangement to hold the material, which is hinged at both ends to a chain or a belt, which in turn moves over fixed path along the drive for conveying purpose. Multiple number of such bins or grippers are used for storage purpose. The chain is driven by a brake gear-motor. As the motor rotates the chain arrangement along with bins or grippers also move such that the material stored is not dropped. Loading/Unloading point is provided at a convenient height for easy material handling by workers.

Main components of vertical storage system are:

1. Frame (Structure)
2. Driver/Driven shafts
3. Driver/Driven sprockets
4. Chain
5. Attachment link
6. Rod
7. Hook (Gripper)
8. Motor

Figure 3.1 shows 3D model of vertical storage system.

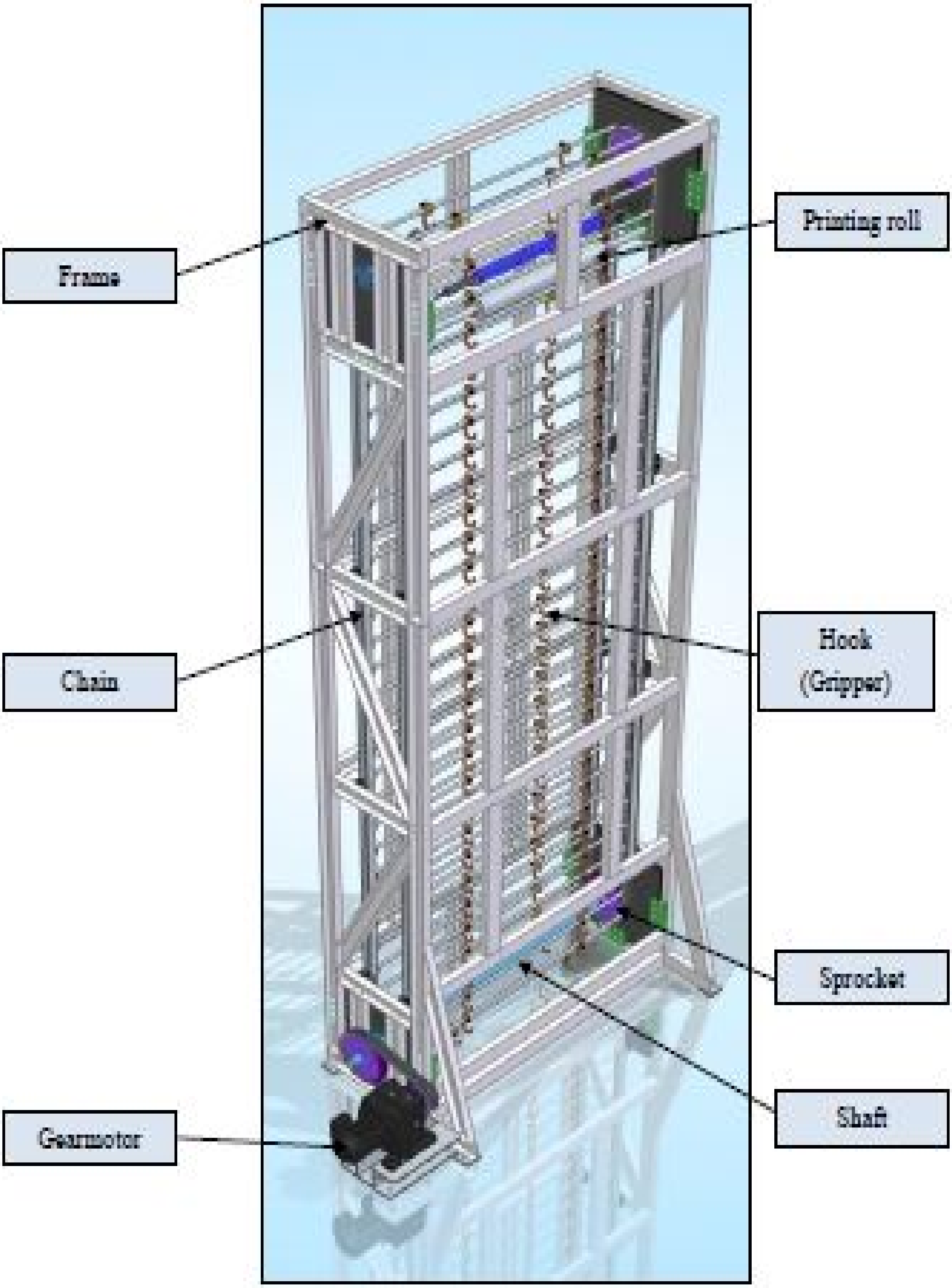


Figure 3.1: 3D model of Vertical Storage system

3.1 Analytical calculations

Storage system is conceptualized for maximum capacity of 62 printing rolls. Design is done such that roll of maximum diameter 250mm, roll of maximum length of 2200 mm can be stored. Maximum mass of single printing roll is considered 50 kg. Self weight of hook assembly and chain itself is also considered while calculations.

Chain selection criteria

Chain pull or Force required to pull rolls F,

$$F = [(\mathrm{n}_r * m_r * 9.81) + (n_a * m_a * 9.81) + (m_c * 9.81)] \tag{3.1}$$

Where,
$\mathrm{n_r}$= No of rolls in system = 62
$\mathrm{m_r}$= Mass of single roll = 50 kg
$\mathrm{n_a}$= No of hook assembly = 62
$\mathrm{m_a}$= Mass of single rod = 15 kg
$\mathrm{m_c}$= Approx mass of chain = 200 kg
Substituting values in above equation we get,

$$F = [(62 * 50 * 9.81) + (62 * 15 * 9.81) + (200 * 9.81)]$$

$$F = 41,496.3N \approx 42000N$$

$$F \approx 42kN$$

Now the no. of chains used is 2, so load is equally distributed on each, Force on single chain $=\frac{42}{2}$= 21 kN

Now selecting a chain with minimum breaking load more than calculated load Selection of chain should be done while keeping Factor of Safety (fos) in mind. Here duplex chain of pitch = 25.4mm is selected as per application and fos required.

Motor selection criteria

Motor used in vertical storage must be able to transmit power even at maximum loading condition i.e. completed filled storage system. Motor must be able to transmit power at constant low speed and high torque as required by the system. And motor must also stop at any instance and should sustain the position at any loading condition. Thus, in order to fulfill the above criteria a Brake geared motor is to be used.

Torque required for carrying the rolls at maximum loading conditions can be given by,

$$T = F * r \tag{3.2}$$

Where,
T = Torque required (Nm)
F = maximum load = 42 kN = 42000 N
r = radius of sprocket $= \frac{(\text{PCDof sprocket})}{2}$ = 0.225 m

$$T = 42000 * 0.225$$

$$T = 9450Nm$$

Now, maximum velocity at which the system should rotate, v = 0.115 m/s

$$rpm(n) = \frac{(v*60)}{2\pi r} \tag{3.3}$$

$$n = \frac{(0.115*60)}{(2*3.14*0.225)}$$

$$n = 4.88rpm \approx 5rpm$$

Therefore, power required can be given by,

$$P = \frac{\text{2nT}}{60} \tag{3.4}$$

Where,
P = power required (watts)
n = output rpm of motor = 5 rpm
T = torque required = 9450 Nm

$$P = \frac{2*3.14*5*9450}{60}$$

$$P = 4945.5\text{watts}$$

$$P = 4.945\text{kW}$$

$$P = 6.62\text{HP}$$

Hence, a brake geared motor of 7.5HP can be selected with 5 rpm as its output.

3.2 Frame (Structure)

Frame or structure of the storage system supports the sub-assemblies and components of the storage system. It also deals with static and dynamic loads without any deflection or distortion. C-channels of structural steel are used for frame structure. Sub-assemblies, driver sprocket assembly and driven sprocket assembly are mounted at bottom and top of the frame respectively. On one side motor mounting is done to support motor. Leveling pads are provided at bottom of the frame for leveling of the system. A 3D model has been developed in Solid Edge ST9 software as shown in Figures 3.2-3.6 .

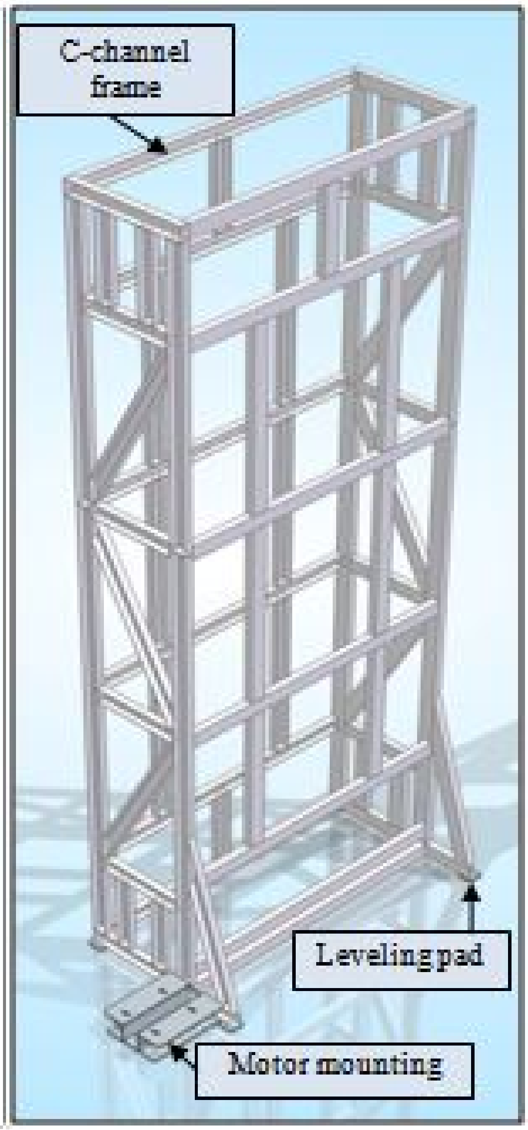
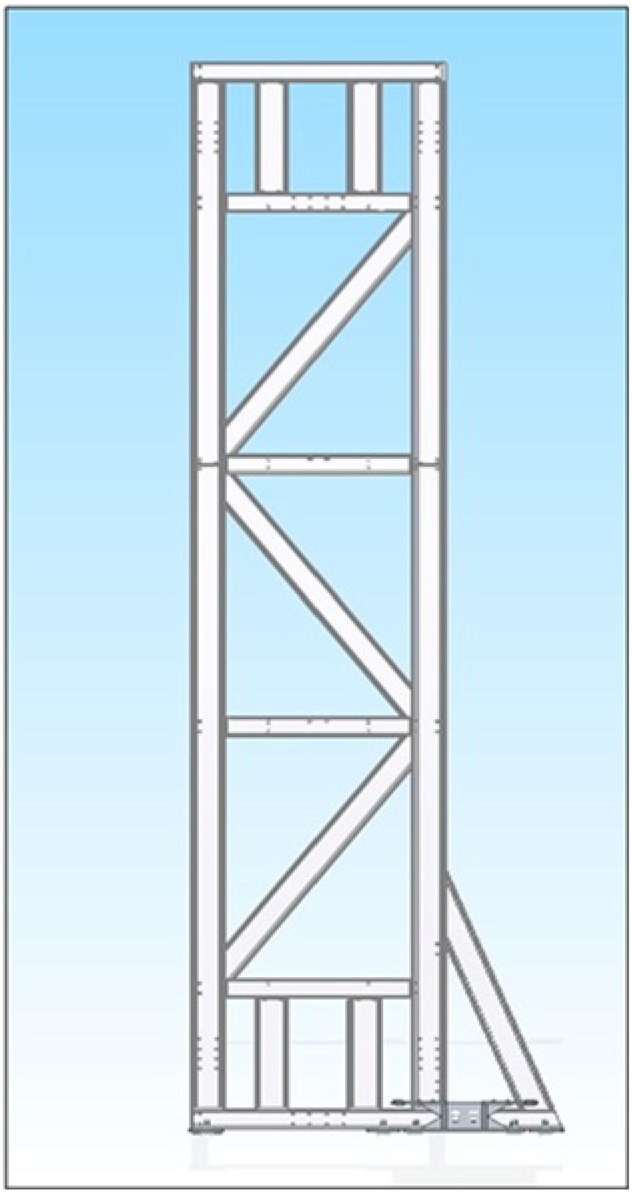


Figure 3.2: Frame with various sub-assemblies mounted

Figure 3.3: C-channel frame



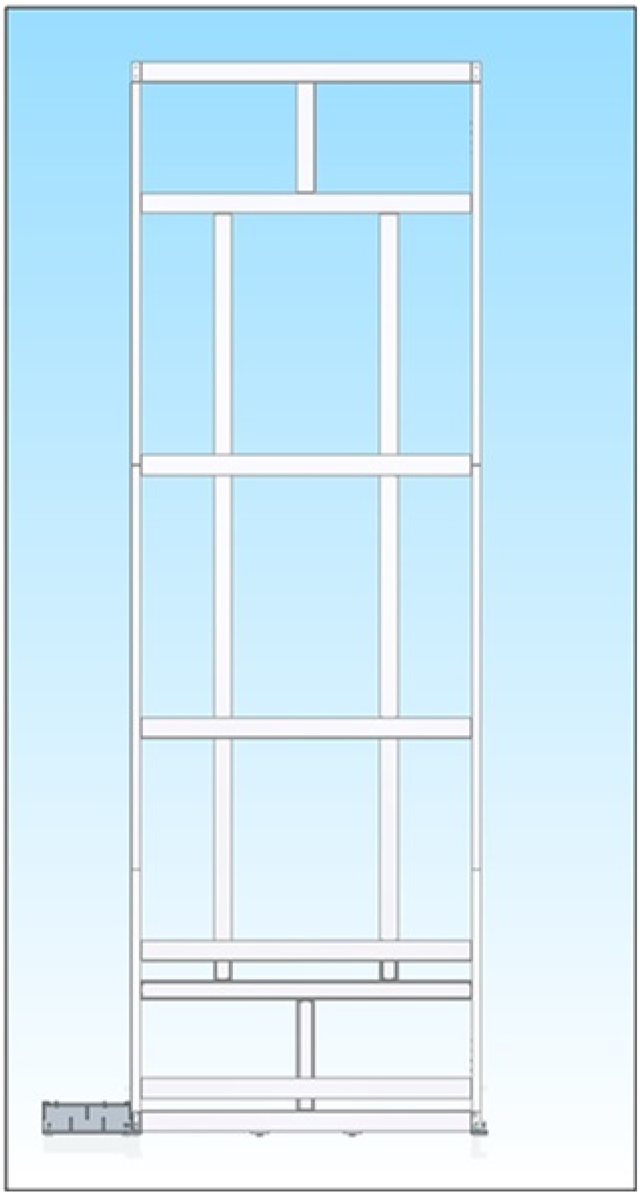


Figure 3.4: Frame LH view

Figure 3.5: Frame front view

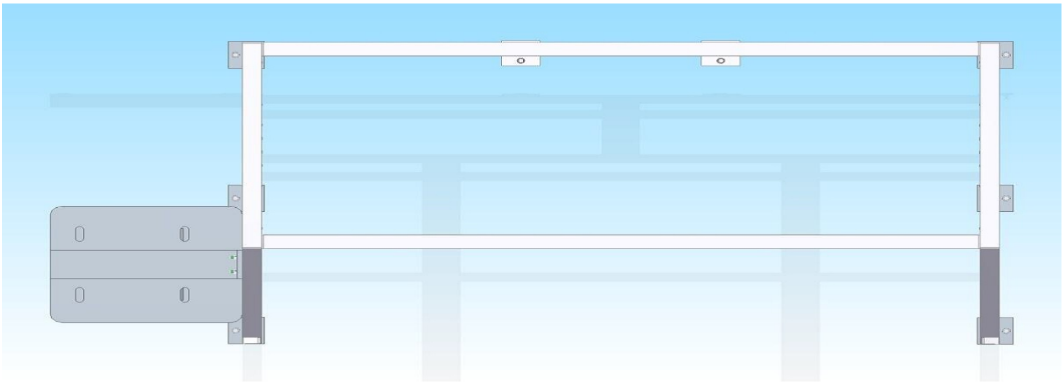


Figure 3.6: Frame top view

3.3 Driver Sprocket Assembly

Driver sprocket assembly or Driver assembly is connected with the motor and is responsible for motion of the system. Assembly consists of driver sprockets, driver shaft, flanges and support plate for the sub-assembly. Driver assembly is mounted on frame with the help of support plates on both sides. Various representations of model for driver sprocket are shown in Figures 3.7-3.11.

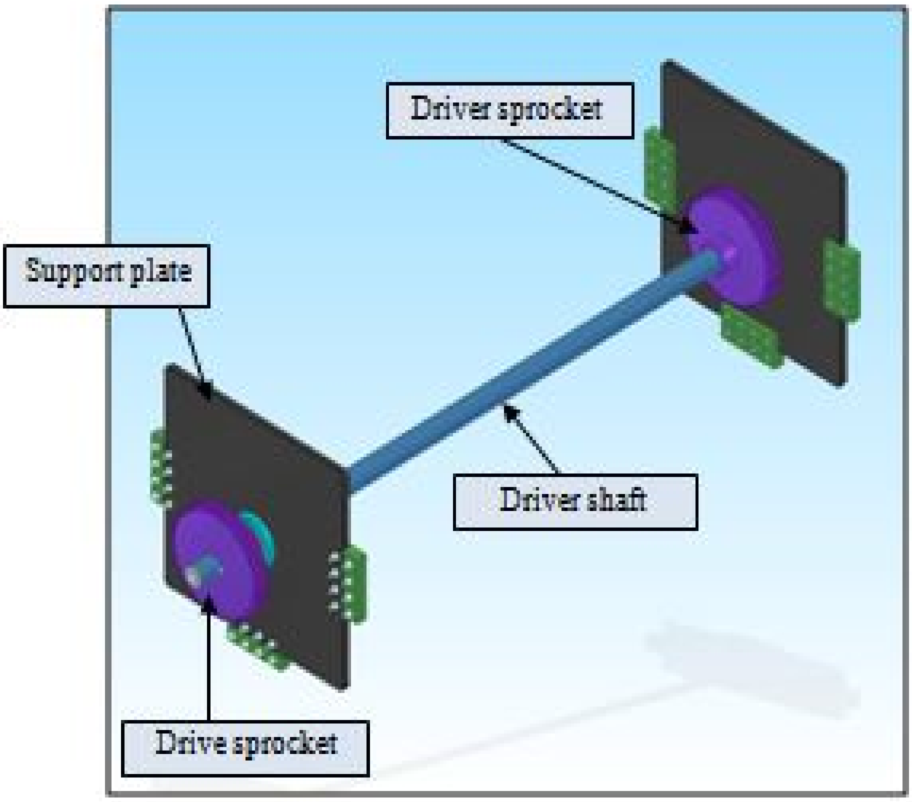


Figure 3.7: Driver sprocket assembly

Sprockets are mounted on driver shaft with the help of Keys, and are held at position with the help of grub screws. Motion is provided by motor to drive sprocket, located outside, which in turn rotates driver shaft. Along with driver shaft driver sprockets also rotates. Flanges are mounted on support plates for support to the driver shaft. Arrangement of double bearing support is provided through flanges at both ends.

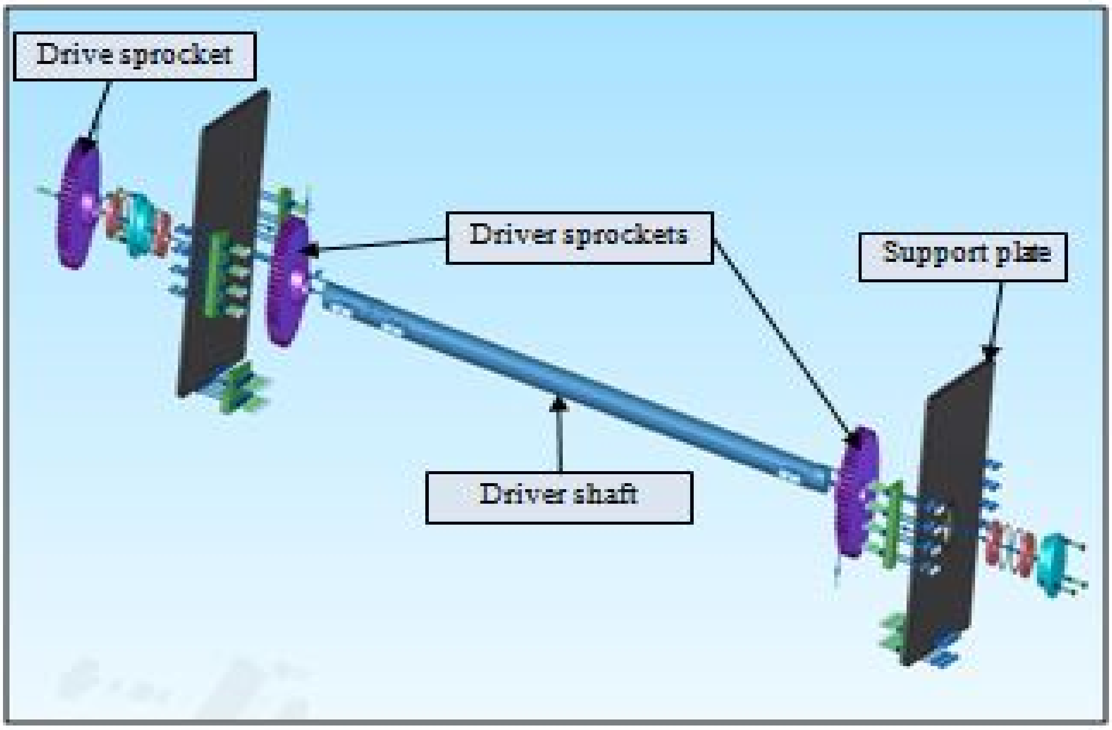


Figure 3.8: Exploded view of Driver sprocket assembly

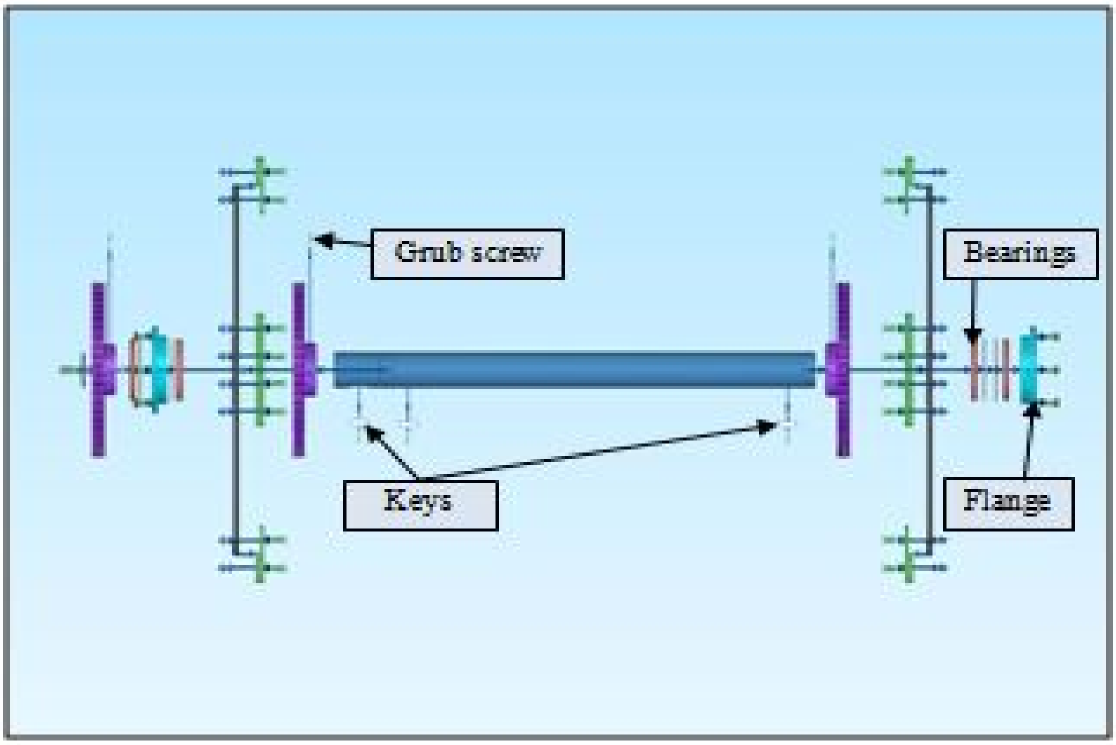


Figure 3.9: Top view of exploded Driver sprocket assembly

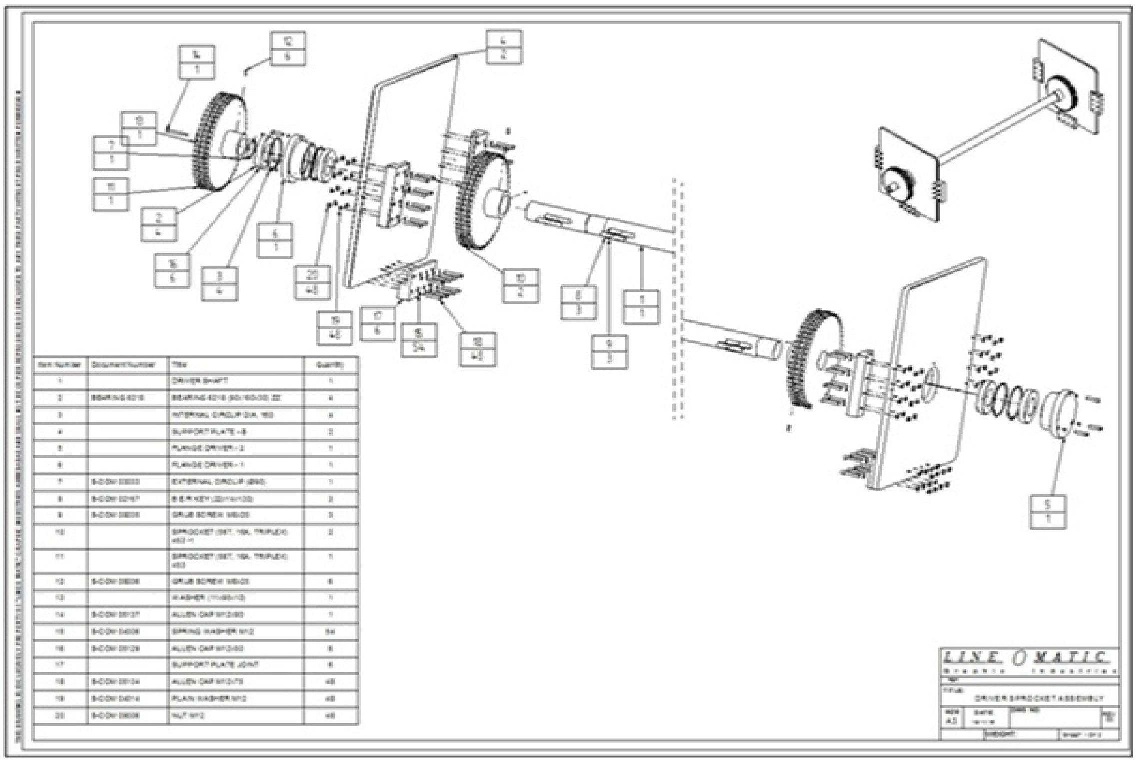


Figure 3.10: Assembly drawing of Driver assembly with part list

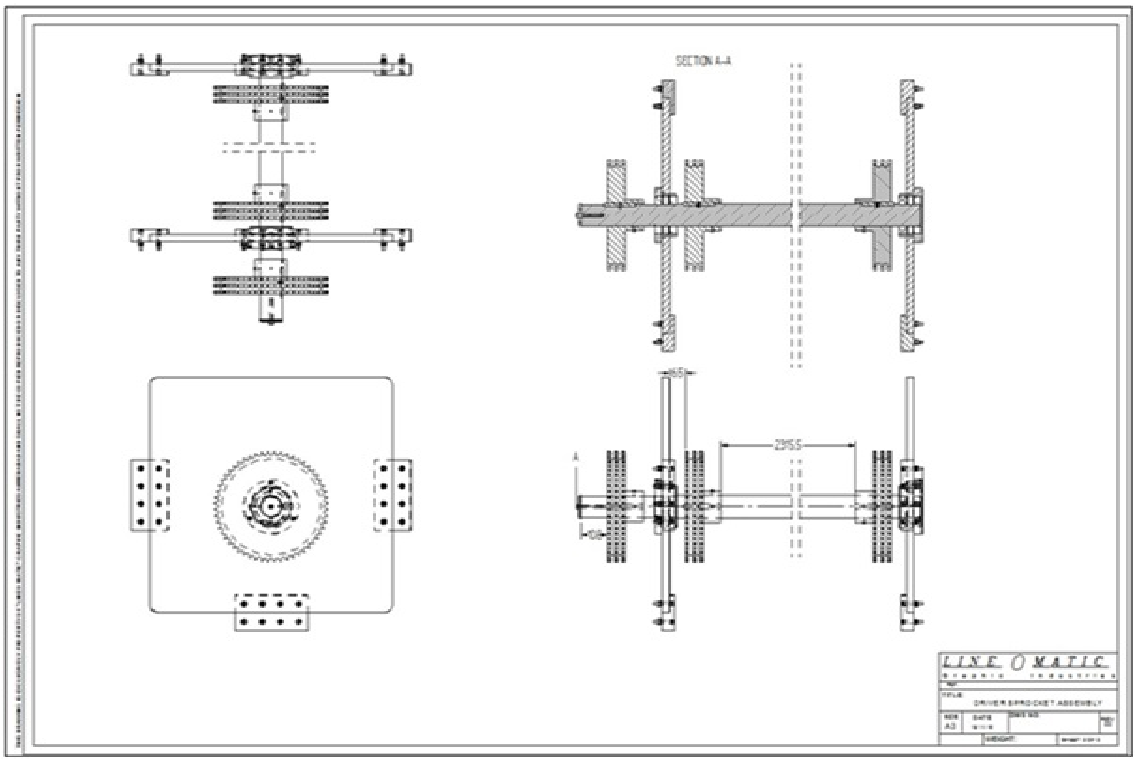


Figure 3.11: Orthogonal views of Driver sprocket assembly

3.3.1 Driver Shaft

Driver shaft is a critical component of the vertical storage system. Driver sprockets are mounted on the shaft itself, thus transmitting load on the driver shaft. Driver shaft itself has to transmit power or motion under the load of the printing rolls. So it is important that the shaft does not fail during working condition. Material for shaft is considered EN8. Calculations for safe shaft diameter is done under bending and torsional moment by maximum principle stress theory. Various models of driver shaft are shown in Figure 3.12 and Figure 3.13.

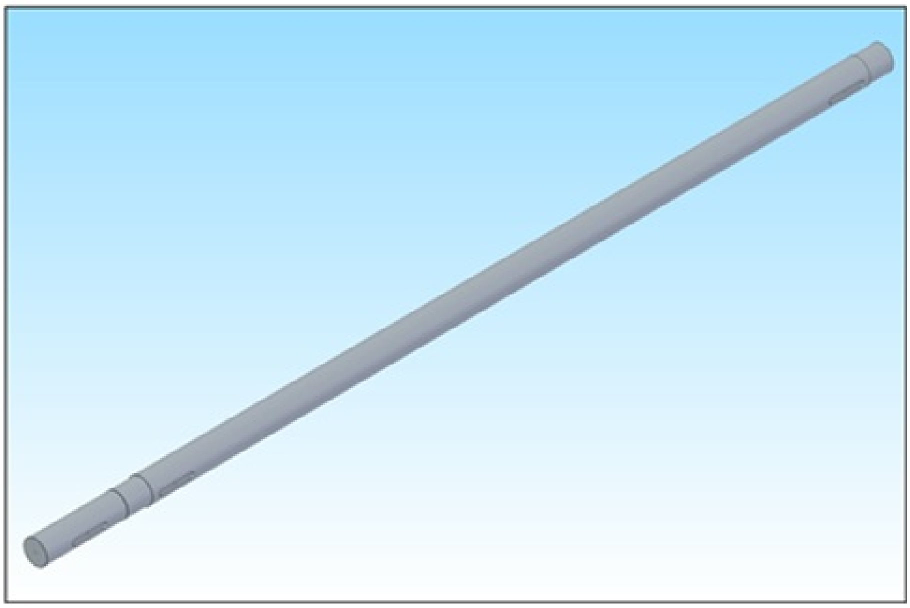


Figure 3.12: Driver shaft

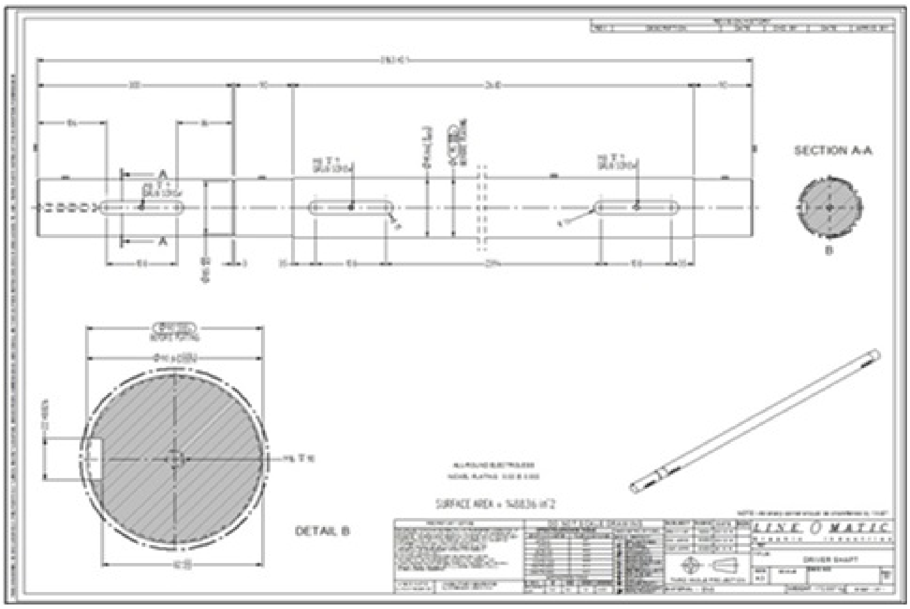


Figure 3.13: Orthogonal views of Driver shaft

Shaft diameter calculation

Driver shaft is subjected to torsional and bending moment while in working condition, where as driven shaft is mainly subjected to bending moment. But calculation here is done taking same conditions for both the shafts. Material of both the shaft is taken EN8. Calculations are done on basis of maximum principle stress theory. Schematic diagram of Driver shaft is shown in Figure 3.14 .

Maximum principle stress, $_1$,

$$_1 = \frac{16}{d^3}\left[M_b + \sqrt{(M_b)^2 + (M_t)^2}\right] \tag{3.5}$$

$$d^3 = \frac{16}{\sigma_1}\left[M_b + \sqrt{(M_b)^2 + (M_t)^2}\right] \tag{3.6}$$

Where,

σ_1= Permissible maximum principle stress (N/mm^2)

d = diameter of shaft

M_b= Bending moment (Nmm)

M_t= torsional moment (Nmm)

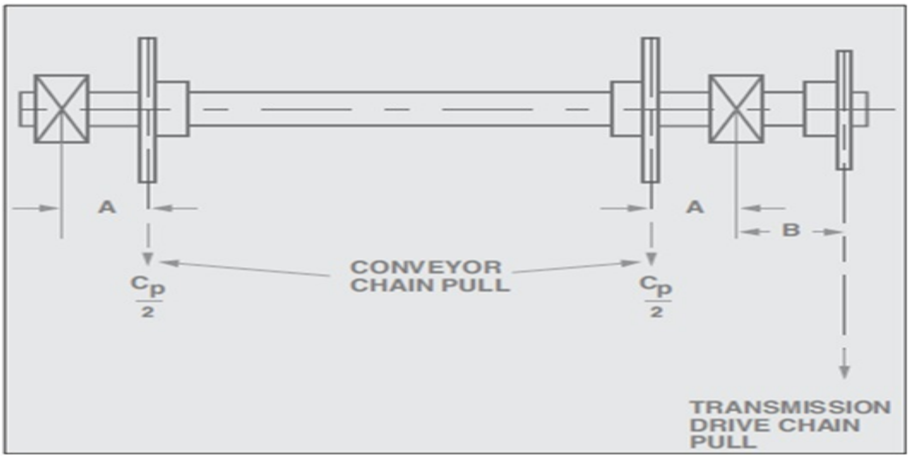


Figure 3.14: : Schematic diagram of Driver shaft

Here,

C_p= chain pull = 42,000 N

A = centre distance between bearing and sprocket = 0.1475 m

B = centre distance between bearing and drive sprocket = 0.150 m

PCD = Pitch circle diameter of sprocket = 0.450 m

Bending moment is induced by transmission drive chain pull and driver chain pull. The greater of the above two bending moments is taken in consideration for calculation of diameter.

Now, assuming both the chains are under equal tension, then the bending moment due to chain pull will be equal to half of total chain pull $\mathrm{C_p}$(N) multiplied by distance A(m). Hence,

$$M_{b1} = \frac{c_p \mathrm{A}}{2} \tag{3.7}$$

$$\mathrm{M_{b1}} = \frac{(42000X0.1475)}{2}$$

$$\mathrm{M_{b1}} = 3097.5Nm$$

Now, the bending moment because of the transmission chain pull will be transmission chain pull (N) multiplied by distance B (m). Hence,

$$\mathrm{M}_{b2} = \text{Transmission chain pull} * B \tag{3.8}$$

$$\text{Transmission chain pull} = \frac{(Torque(Nm) * 2)}{(\text{PCD of drive Sprocke}t)} \tag{3.9}$$

$$\text{Transmission chain pull} = \frac{(9450{*}2)}{0.453}$$

$$\text{Transmission chain pull} = 41,721.85N$$

Now substituting value of transmission chain pull in equation of M_{b2} we get,

$$M_{b2} = 41721.85 * 0.150 = 6258.27Nm$$

M_{b2} is greater of both the bending moments, thus using bending moment due to transmission chain pull in calculation.

$$\mathrm{M_b} = 6258.27Nm = 6258270Nmm$$

$$M_t = \frac{(C_p{*}\ \mathrm{PCD})}{2} = 9450Nm = 9450000Nmm$$

$$_1 = \frac{\sigma_{yt}}{\mathrm{fos}} = \frac{465}{2} = 232.5\frac{\mathrm{N}}{\mathrm{mm}^2}$$

Now, substituting all the values in equation derived above to obtain safe value of shaft diameter,

$$d^3 = \frac{16}{\sigma_1}\left[M_b + \sqrt{(M_b)^2 + (M_t)^2}\right]$$

$$d = 72.77mm \approx 73mm$$

$$d \approx 80mm \text{(standard value)}$$

Thus, Safe diameter for shafts to work proper without failure is 73mm which is rounded off to 80 mm standard value, for ease of manufacturing.

3.4 Driven Sprocket Assembly

Driven sprocket assembly or Driven assembly is connected with driver assembly through chains on both sides. Assembly consists of driven sprockets, driven shaft and support plate for the sub-assembly. Driven assembly is mounted on frame with the help of support plates on both sides. Various types of models for driven sprocket assembly are shown in figure 3.15-3.19.

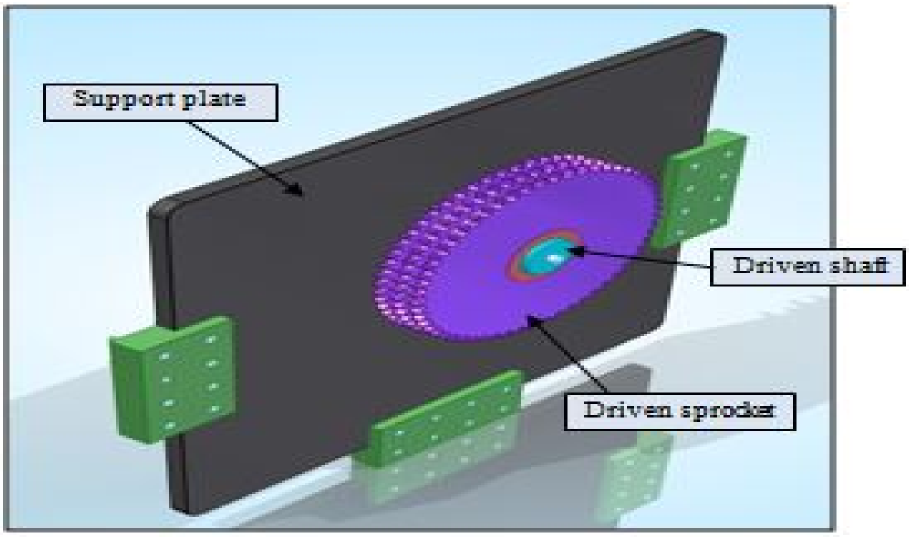


Figure 3.15: Driven sprocket assembly

Sprockets are mounted on two bearings on both sides of each sprocket, which are then mounted on driven shaft. Driven shaft is a fixed one. It is bolted to support plate, as driven sprocket rotates over bearings. Thus, there is no effect of torque on the driven shaft. Arrangement of double bearing support same as driver shaft is provided in this assembly also.

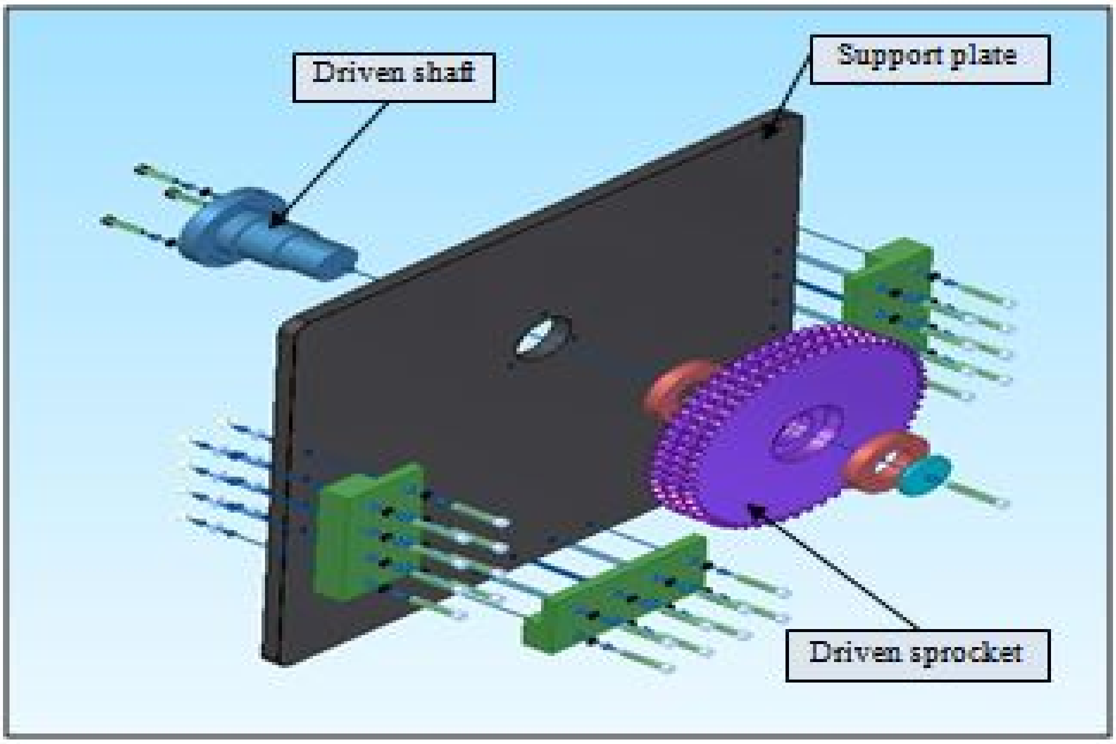


Figure 3.16: Exploded view of Driven sprocket assembly

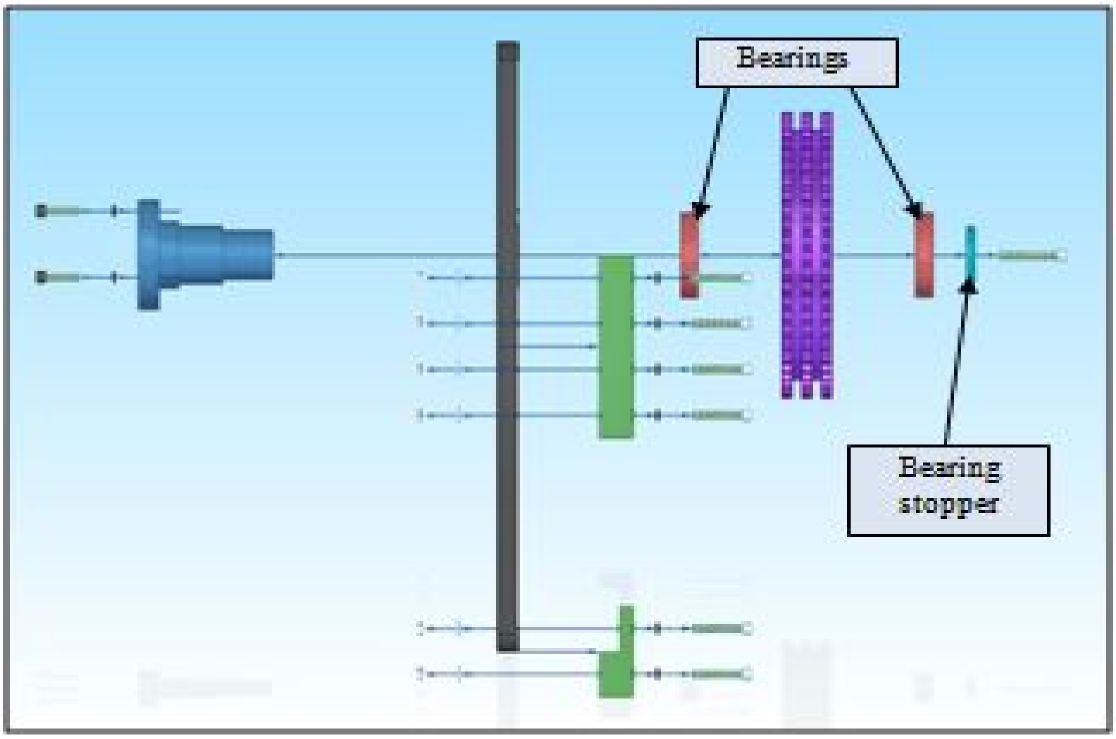


Figure 3.17: Exploded view of Driven sprocket assembly

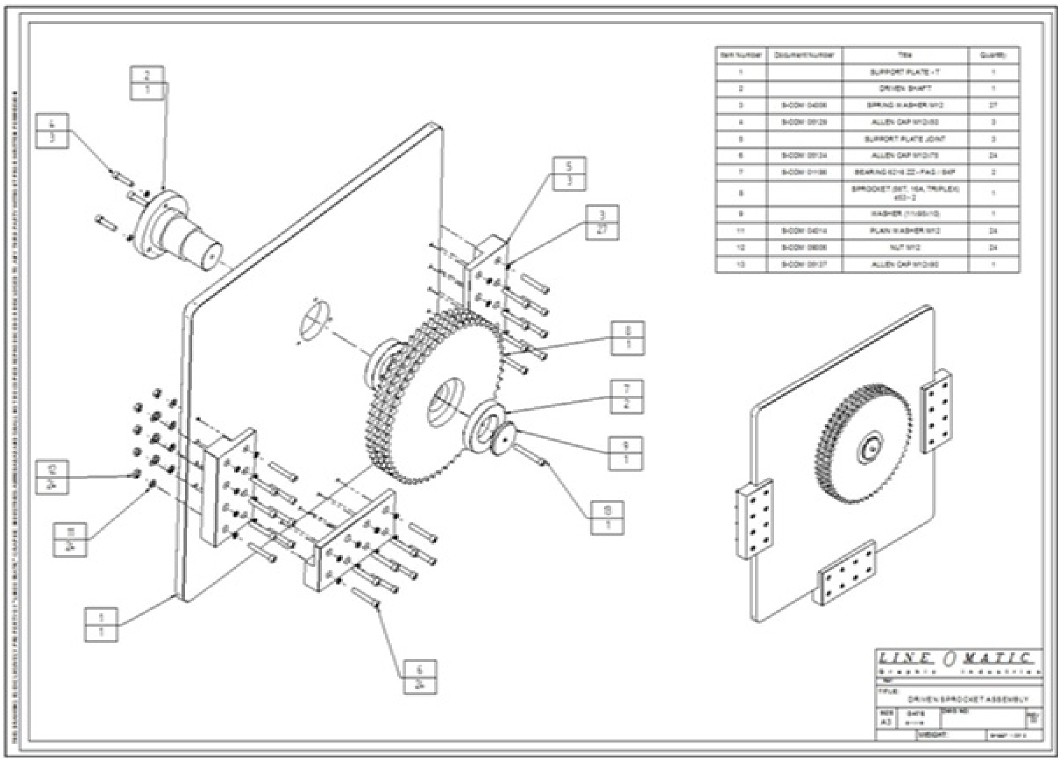


Figure 3.18: Assembly drawing of Driven assembly with part list

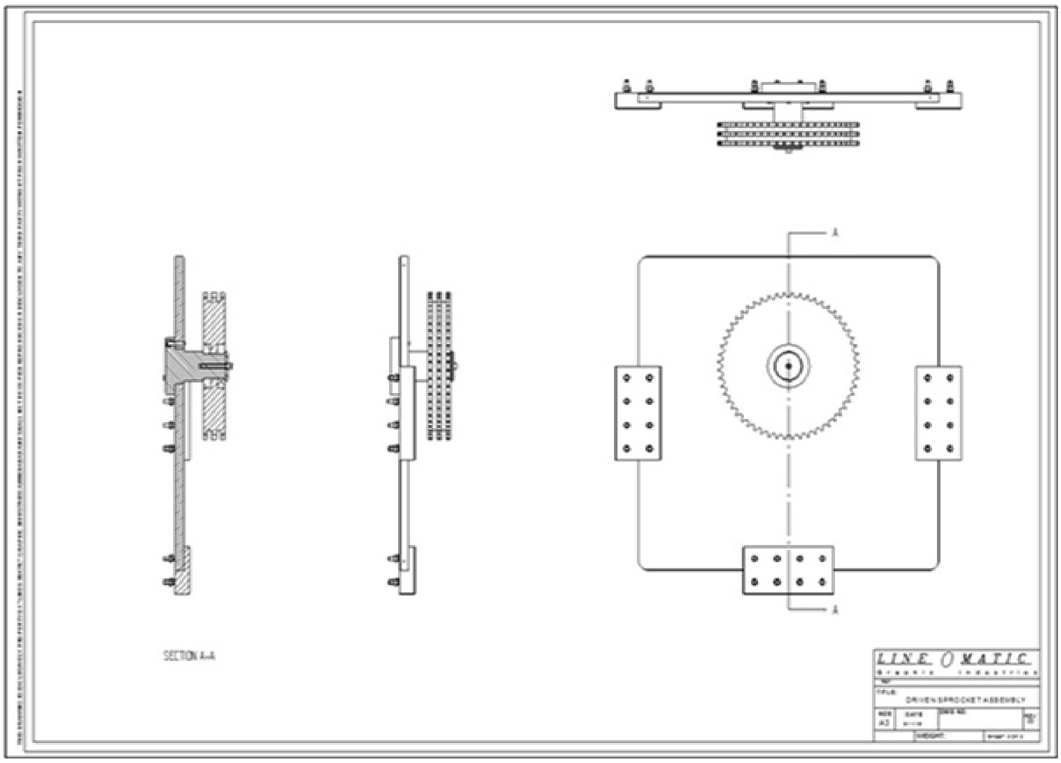


Figure 3.19: Orthogonal views of Driven sprocket assembly

3.4.1 Driven Shaft

Driven shaft is also a critical component of the vertical storage system. Driven sprockets are mounted on bearings which are mounted on driven shaft, thus transmitting negligible torsional load on the driven shaft. Driven shaft has to hold under the load of the printing rolls. So it is important that the shaft does not fail during working condition. Material for shaft is considered EN8. Calculations for safe shaft diameter is done similarly as driven shaft and similar results are derived. Driven shaft is designed such that it is an single piece component for flange and shaft. Thus eliminating need of flange in driven assembly. A stopper is provided at the end of the shaft to limit or stop the movement of bearing in linear direction. Model and orthogonal view of driven shaft are represented in Figure 3.20 and Figure 3.21 respectively.

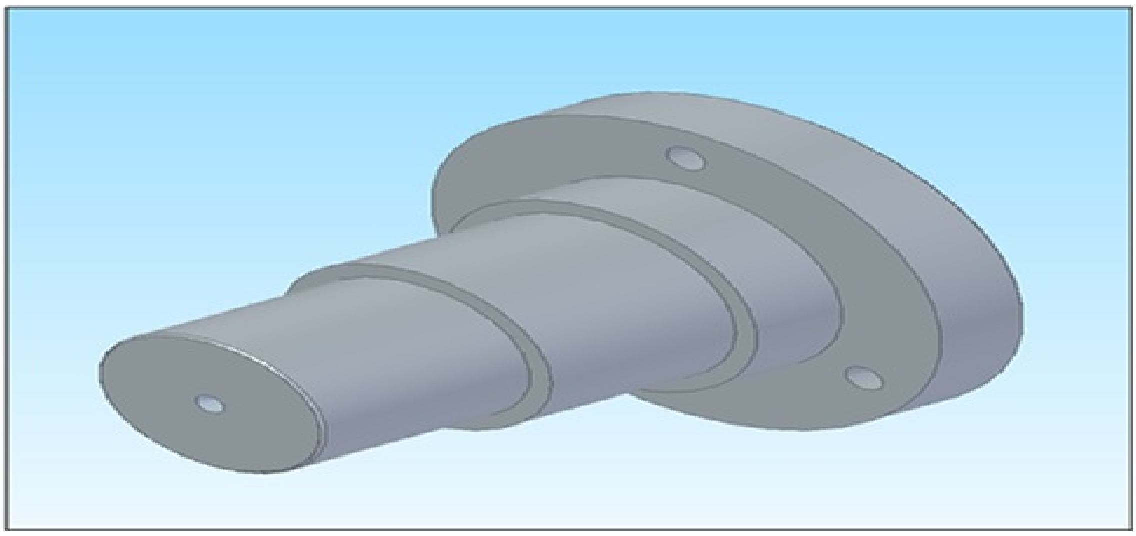


Figure 3.20: Driven shaft

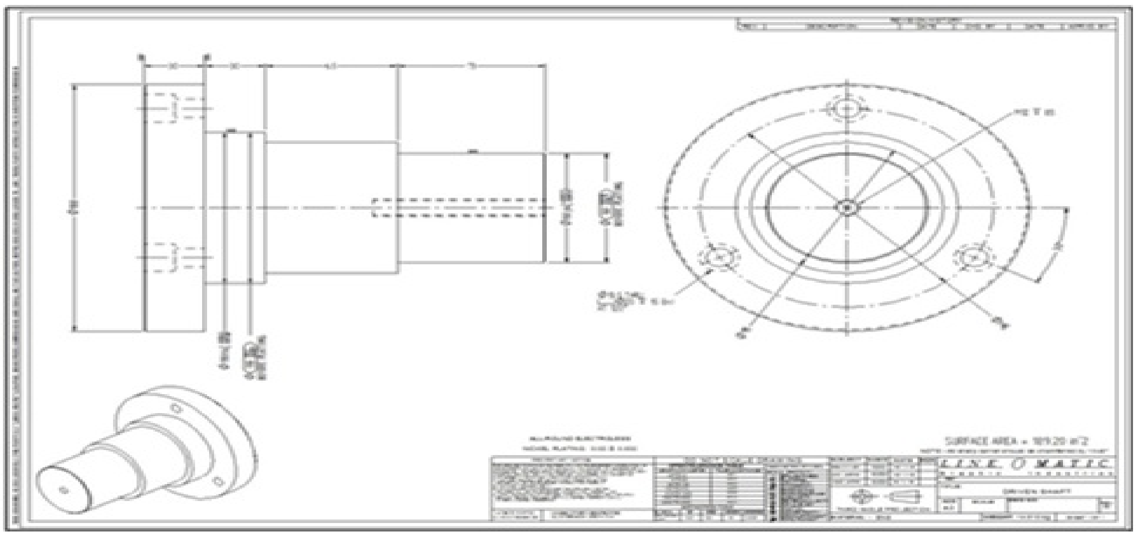


Figure 3.21: Orthogonal views of Driven shaft

3.5 Hook/Gripper Assembly

Hook or Gripper assembly is the one which is in direct contact with the printing rollers. It consists of attachment links, bush, rod, stoppers and hook. Attachment links are used to attach assembly with the chain on both sides, so it moves along with the chain. Bush is used to constrain movement of attachment link. The Rod is a cylindrical component which is a joining component between chain on both sides. Stoppers are mounted over rod over which hook is mounted. This whole assembly of stoppers and hook can move in linear as well as rotary motion, thus providing hinge effect for the stored printing roll and it does not allow the roll to fall while moving along the path of chain. The position of hooks can be adjusted as per requirement of rolls by moving it along the rod. Figure 3.22-3.26 shows different types modeling views for Hook/Gripper Assembly.

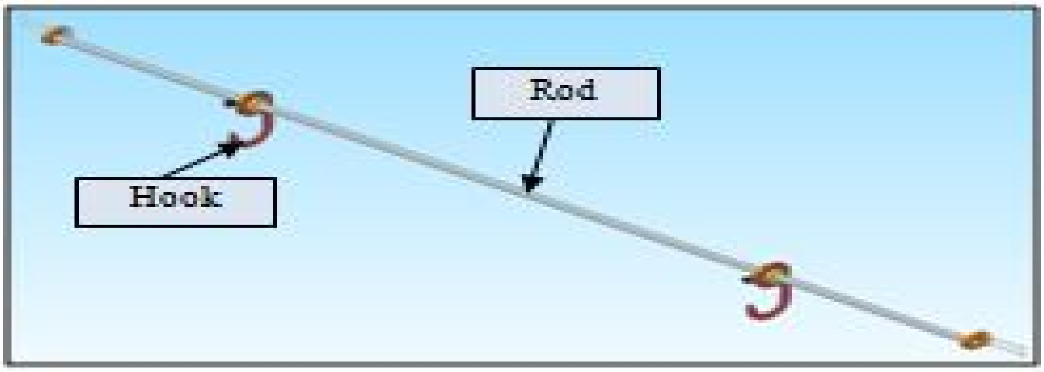


Figure 3.22: Isometric view of Hook/Gripper assembly

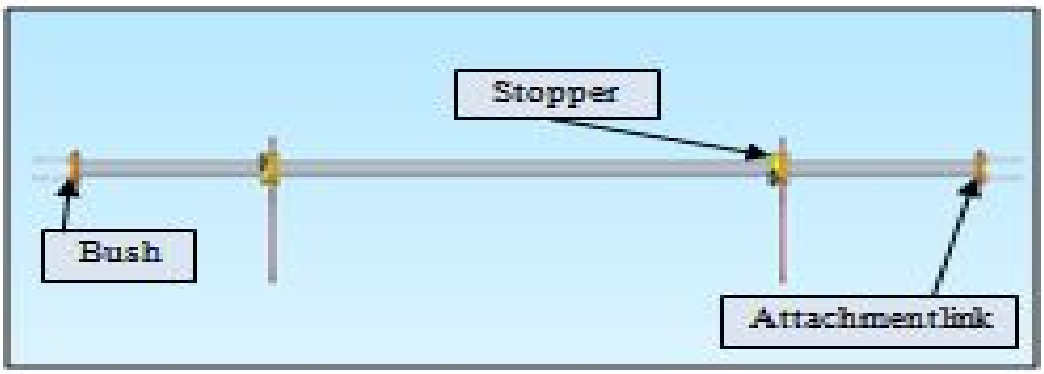


Figure 3.23: Front view of Hook/Gripper assembly

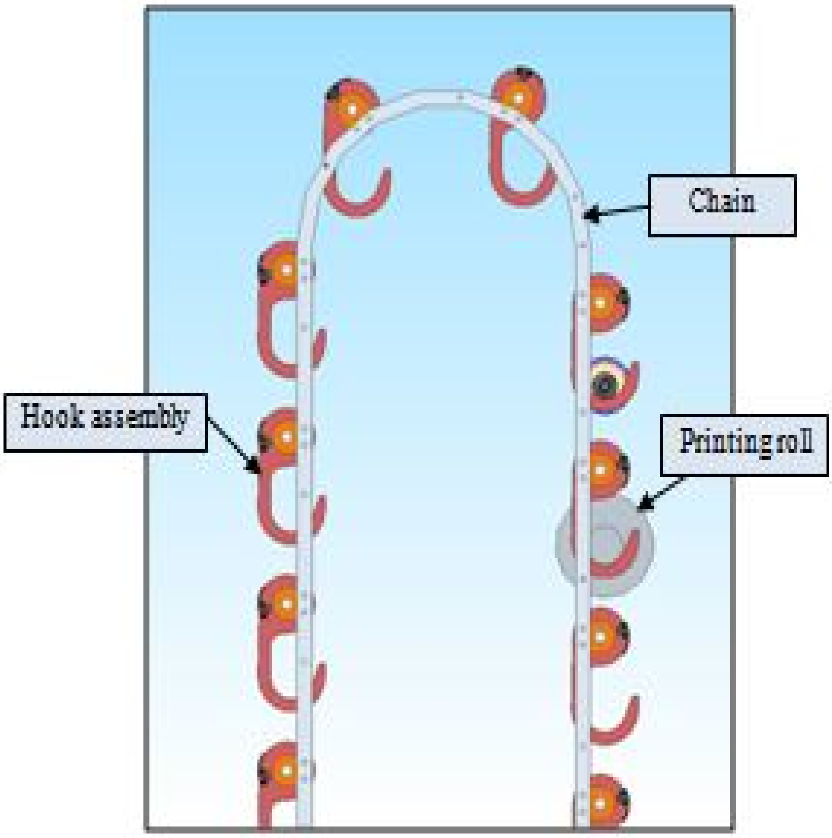


Figure 3.24: Descriptive view of Hook/Gripper assembly

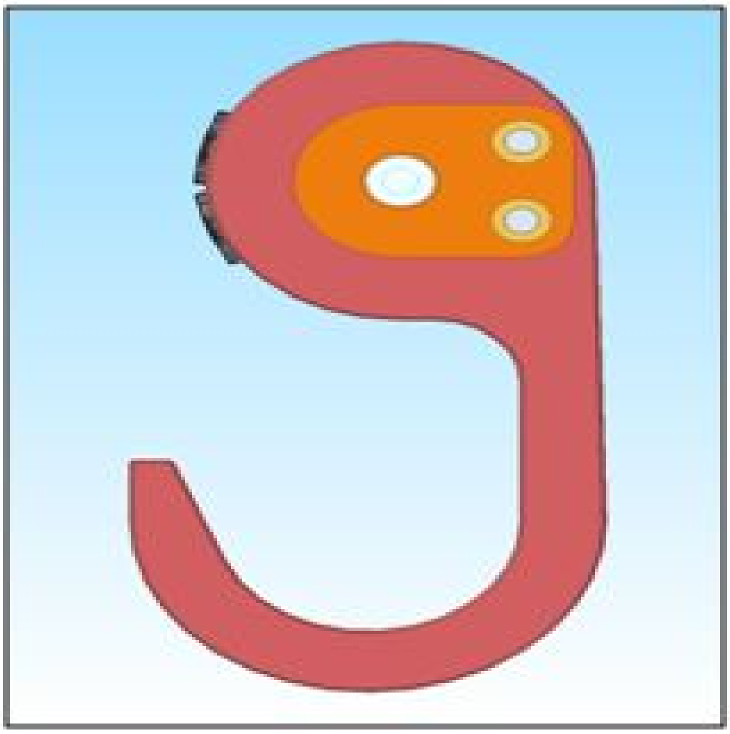


Figure 3.25: RHS view of Hook/Gripper assembly

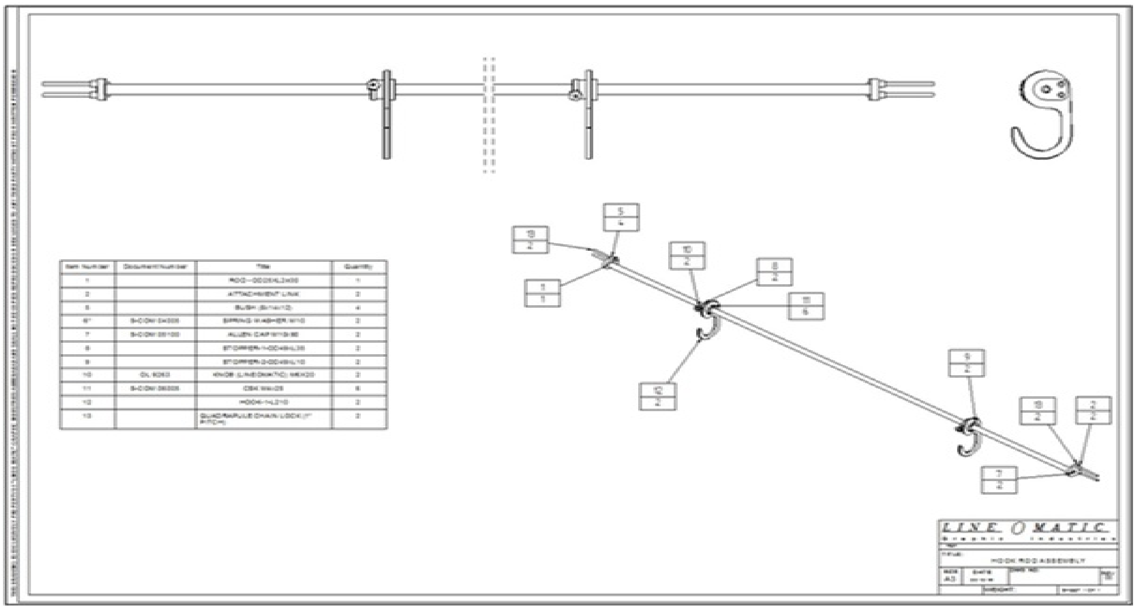
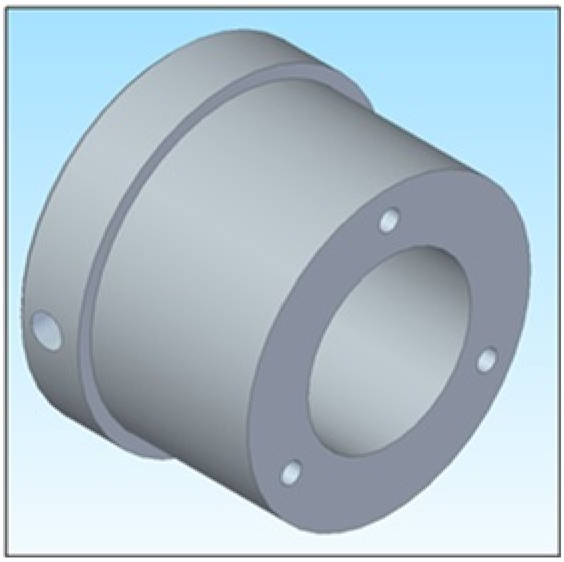


Figure 3.26: Assembly drawing of Hook/Gripper assembly with part list

3.5.1 Stoppers

Stoppers are cylindrical shaped component mounted on rod for restricting linear movement of the hook while allowing free rotary motion. Figure 3.27 and Figure 3.28 shows two different types of stoppers.



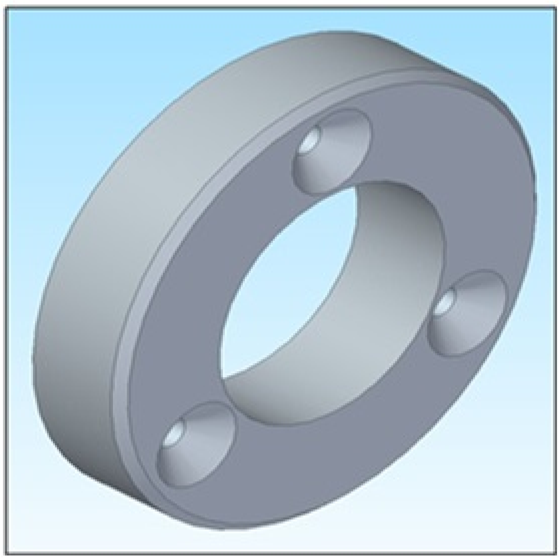
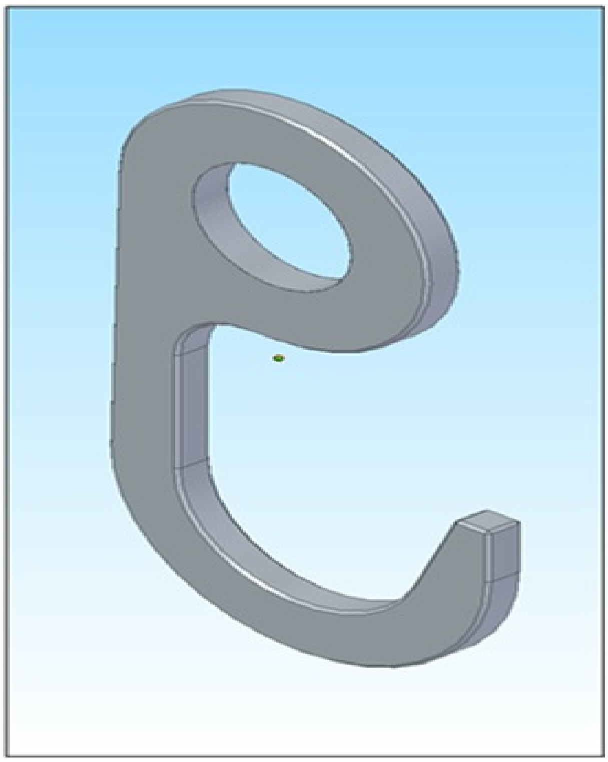


Figure 3.27: Stopper-1

Figure 3.28: Stopper-2

3.5.2 Hook

3.5.2 Hook Hook or Gripper is the component which remains directly in contact with the printing rolls. Its function is to hold the roll throughout the storage time without dropping it at any instance. Hook is mounted on stoppers which restricts its linear motion but allows free rotary motion. Material used for hook is Mild Steel (MS). Figure 3.29 and Figure 3.30 shows different views of Hook.



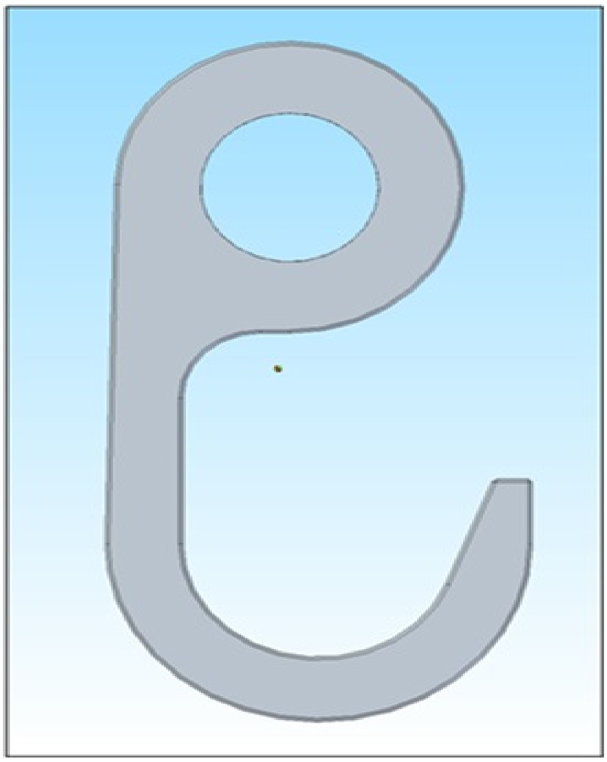


Figure 3.29: Isometric view of hook

Figure 3.30: Hook

3.5.3 Rod

Rod is cylindrical component, which join chains on both sides. It distributes the load of printing roll equally to both chains. Material used is Mild Steel (MS). Figure 3.31 shows model of rod.

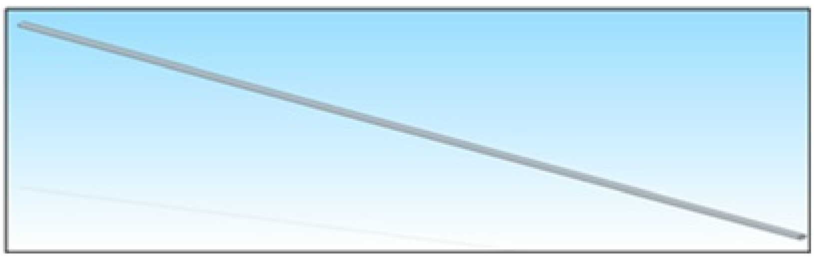


Figure 3.31: Rod

Calculation for Rod diameter

Rod is subjected to bending moment while in working condition, where it is fixed on both sides. Calculation here is done taking condition for bending moment only. Figure 3.32 displays load distribution over entire rod. Material of rod is taken Mild Steel (MS). Calculations are done on basis of maximum principle stress theory.

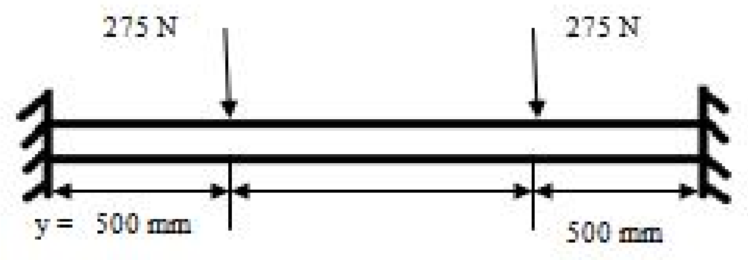


Figure 3.32: Load distribution over rod

$$_1 = \frac{32M_b}{d^3} \tag{3.10}$$

$$\mathrm{d}^3 = \frac{32M_b}{\sigma_1} \tag{3.11}$$

Where,
$_1$= Permissible maximum principle stress (N/mm^2)
d = diameter of rod; $\mathrm{M_b}$ = Bending moment (Nmm)

$$_1 = \frac{\sigma_{yt}}{\mathrm{fos}} = \frac{250}{2} = 125N/\mathrm{m}m^2$$

where, $_{yt}$ of Mild Steel is 250 N/mm^2 and taking FOS = 2

$$\mathrm{M_b} = \frac{\mathrm{FŒy}}{2} = 137500Nmm$$

$$\mathrm{M_b} = \frac{550Œ500}{2} = 137500Nmm$$

Now, substituting values in equation derived above to obatin safe value of rod diameter, we get:

$$\mathrm{d}^3 = \frac{32Œ137500}{3.14Œ125}$$

$$d = 22.38mm{\approx}23mm$$

$$d{\approx}25mm(standardvalue)$$

3.6 Assembly

3D model of Vertical storage system assembly is shown in Figure 3.33 and Figure 3.34 shows cross-sectional view of vertical storage assembly

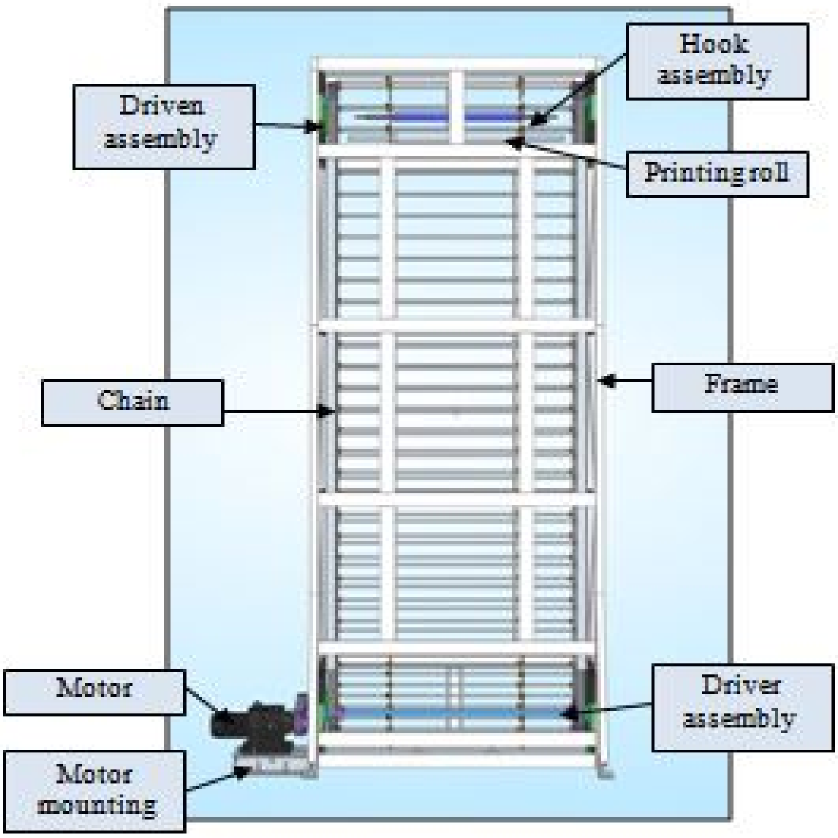


Figure 3.33: 3D model of complete assembly

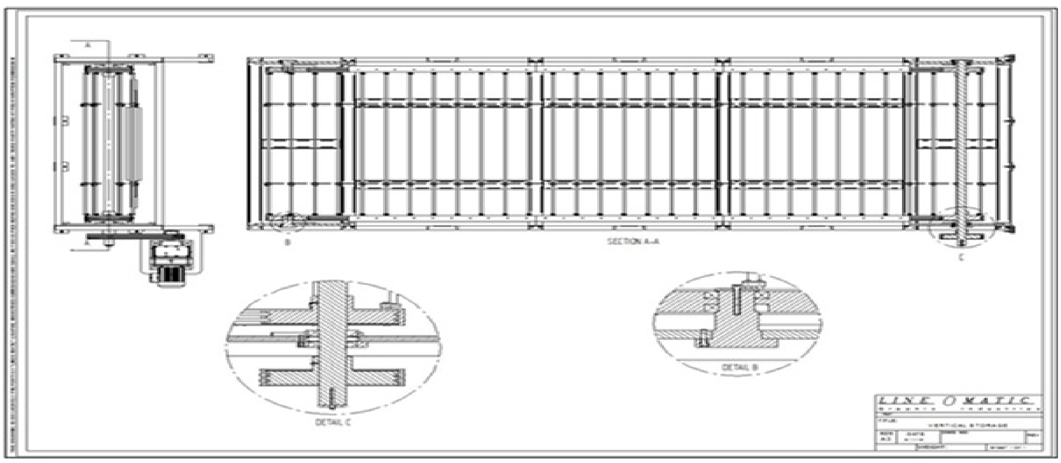


Figure 3.34: Cross-section view of complete assembly

Chapter 4

FEA Simulation

FEA Simulation of the designed components are carried out in order to validate that the parts what we have designed are safe in it is working condition or they may fail in while working in loaded condition. We have designed here many different parts of the Vertical Storage System for the maximum loading condition. Now it is required to validate safety of designed parts while it is in loading condition. FEA Simulation for static conditions of the parts is carried out.

4.1 Frame (Structure)

Frame or structure of the storage system supports the sub-assemblies and components of the storage system. It also deals with static and dynamic loads without any deflection or distortion. Sub-assemblies, driver sprocket assembly and driven sprocket assembly are mounted at bottom and top of the frame respectively. Table 4.1 gives details of material properties for frame.

Analysis of the frame is carried out for static loading conditions. Considering weight of maximum number of rolls stored, sub assemblies and self weight of the frame itself load of 100kN is applied on the frame as shown in the loading Figure. Bottom surface of the frame is fixed constrained.

By the simulation, as shown in Figure 4.1-4.4, we obtain result that maximum stress induced is 78MPa and maximum displacement is 0.7mm, Both values are below than allowable stress and displacement values. So we can say that our design for frame under static condition is safe. Table 4.1 lists down material properties for Frame.

Table 4.1: Material properties for Frame

Properties	Values
Materials	Structural Steel
Modulus of Elasticity	200GPa
Yield strength	250 MPa
Tensile ultimate strength	450 MPa
Mass Density	7850 Kg/m^3
Possion Ratio	0.30

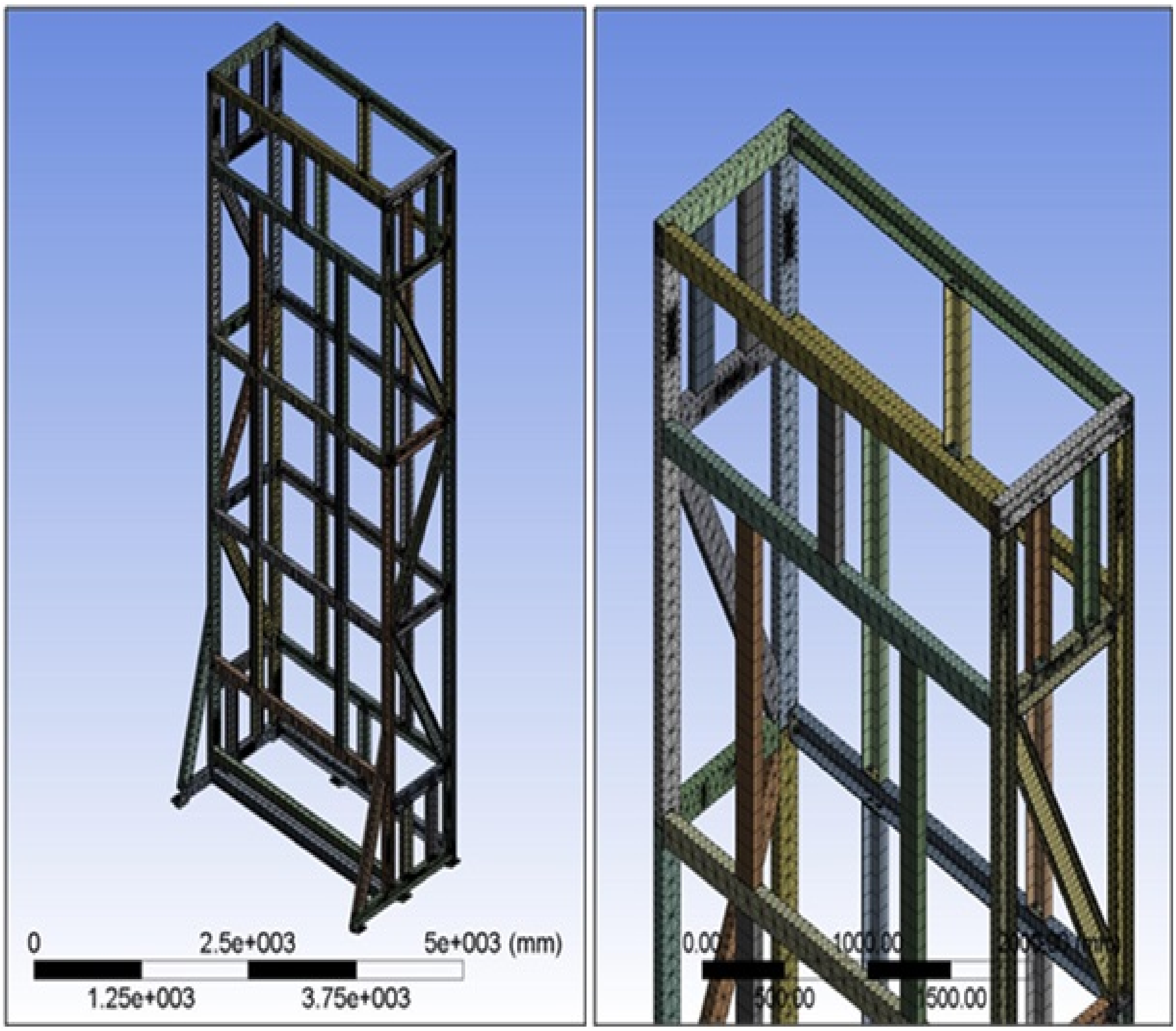


Figure 4.1: Meshed geometry of Frame

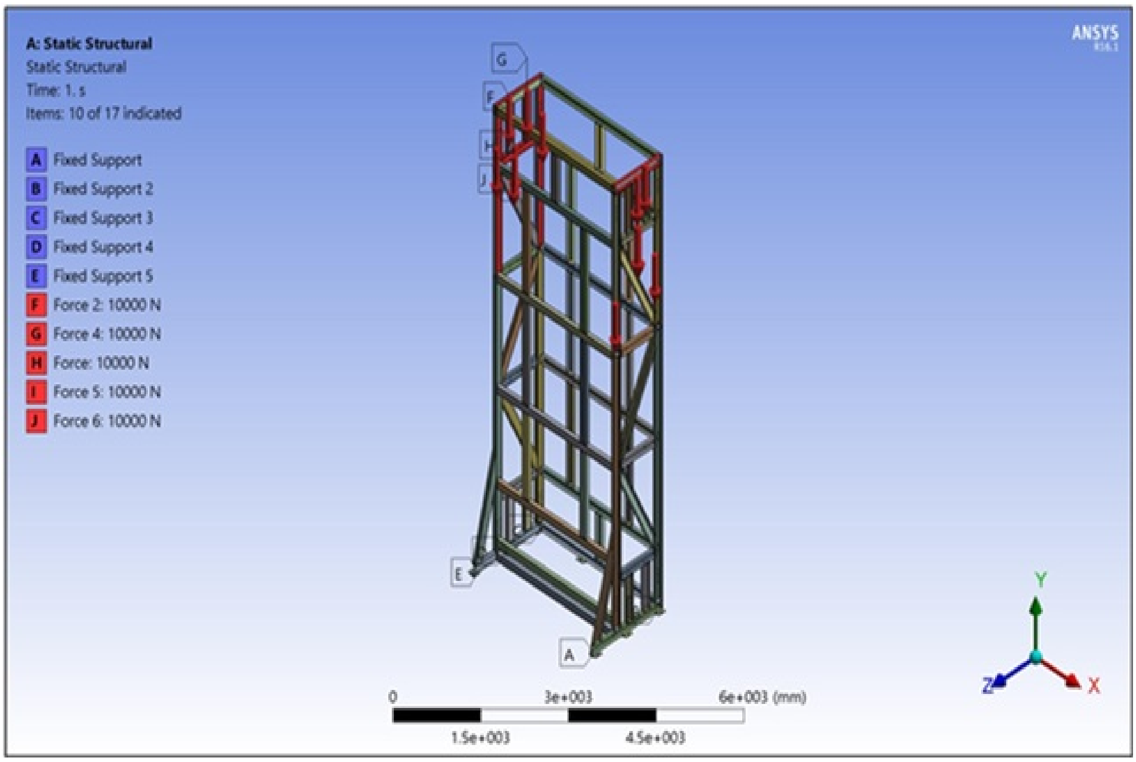


Figure 4.2: Loading condition for Frame

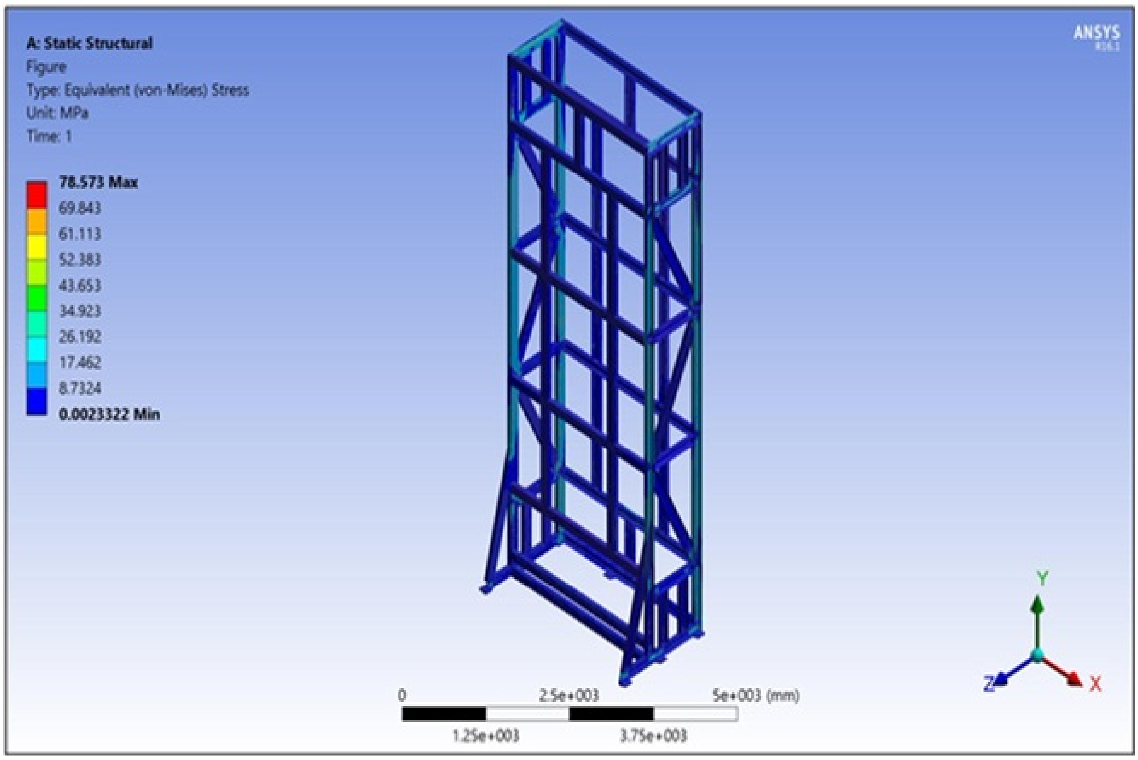


Figure 4.3: Stress induced in Frame

4.2 Driver Shaft

Driver shaft is a critical component of the vertical storage system. Driver sprockets are mounted on the shaft itself, thus transmitting load on the driver shaft. Driver shaft itself has to transmit power or motion under the load of the printing rolls. So it is important that the shaft does not fail during working condition. Table 4.2 gives details of material properties for driver shaft.

Considering weight of maximum number of rolls stored, torque transmitted and self weight of the shaft itself load of 40kN and torque of 8,000Nm is applied on the shaft as shown in the loading Figure. Bearing loads are applied at both ends.

By the simulation, as shown in Figure 4.5-4.7, we obtain result that maximum stress induced is 204MPa. Obtained value is below than allowable stress value. So we can say that our design for driver shaft is safe.

Table 4.2: Material properties for Driver Shaft

Properties	Values
Materials	EN8
Modulus of Elasticity	200GPa
Yield strength	280 MPa
Tensile ultimate strength	510 MPa
Mass Density	7845 Kg/m^3
Possion Ratio	0.29

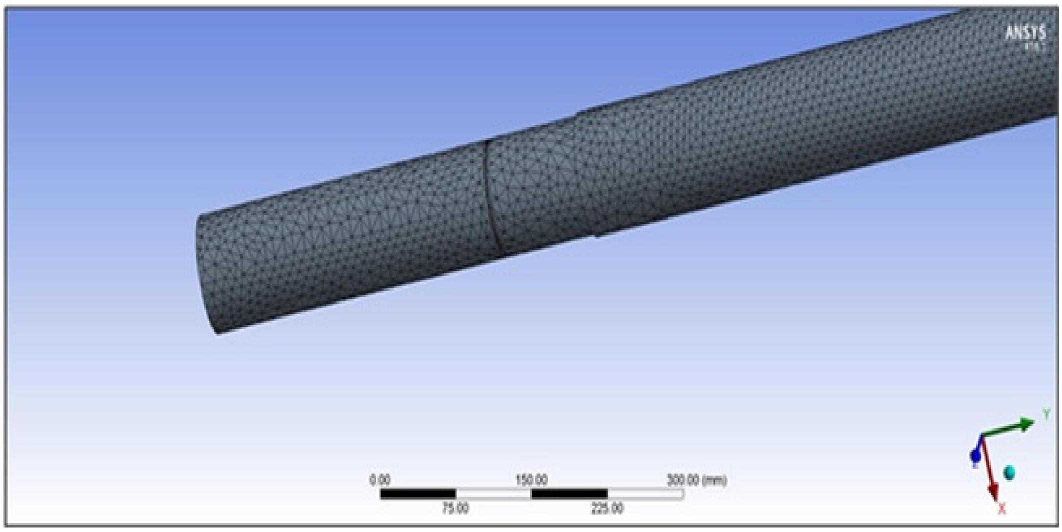


Figure 4.4: Meshed geometry of Driver shaft

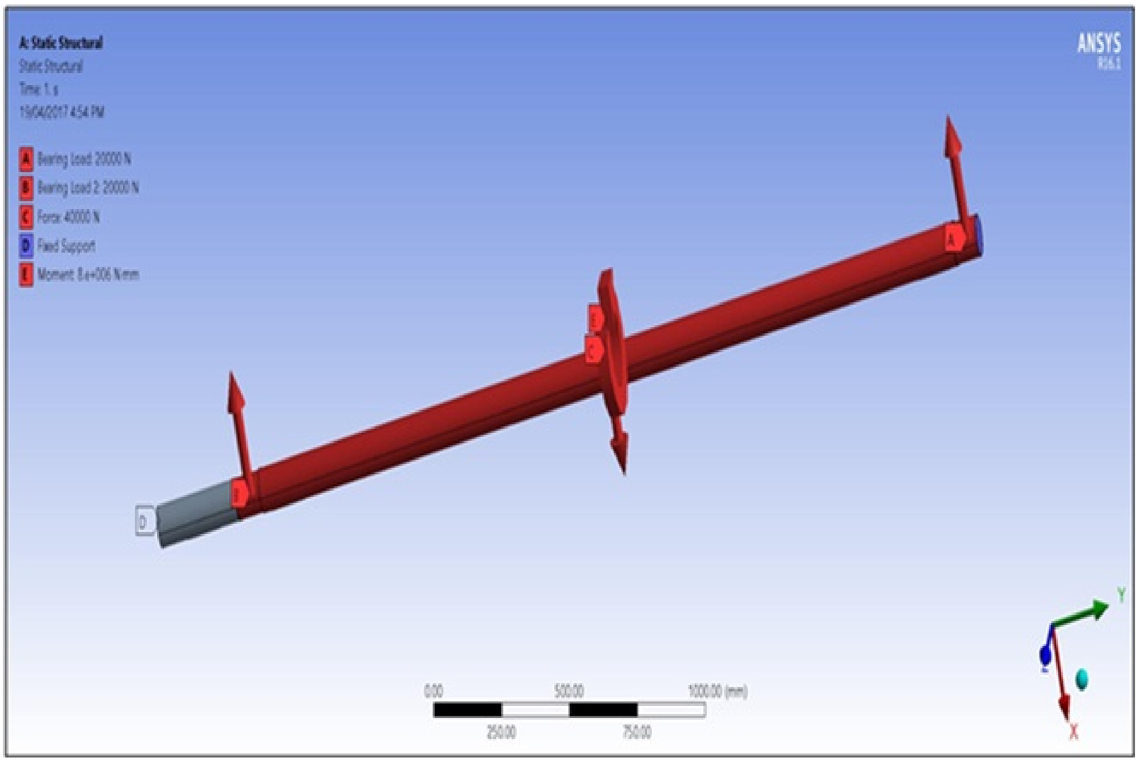


Figure 4.5: Loading condition for Driver shaft

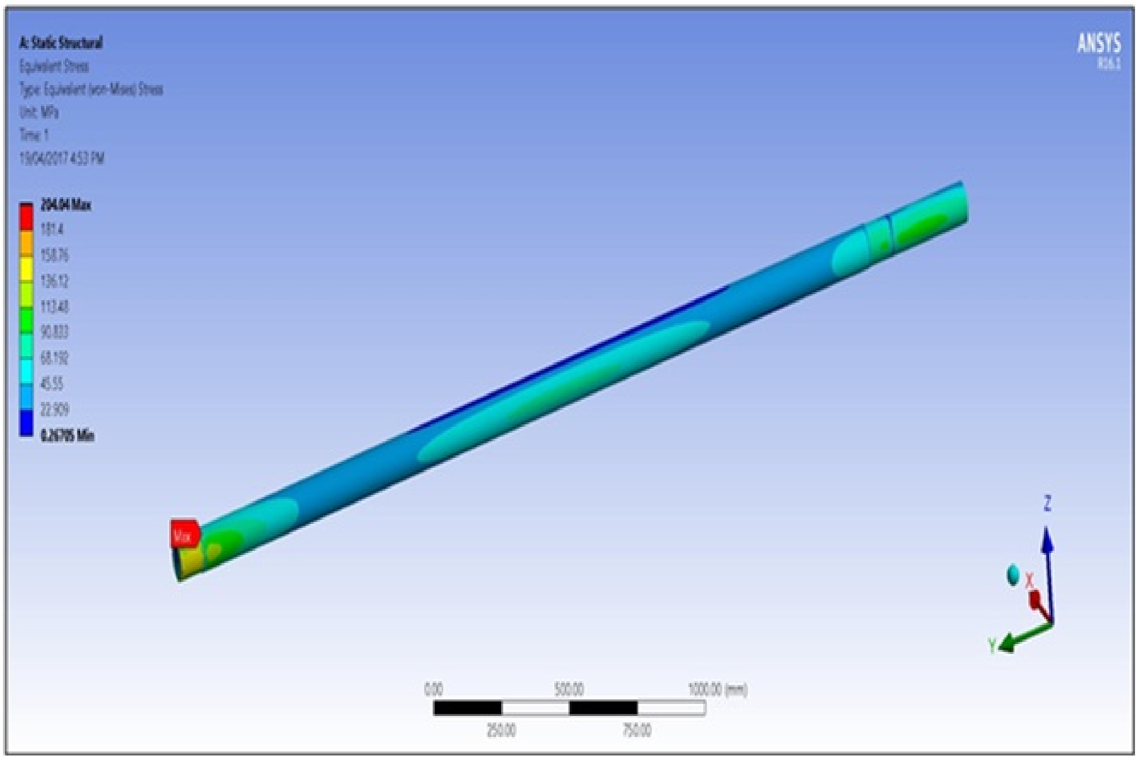


Figure 4.6: Stress induced in Driver shaft

4.3 Driven Shaft

Driven shaft is also a critical component of the vertical storage system. Driven sprockets are mounted on bearings which are mounted on driven shaft, thus transmitting negligible torsional load on the driven shaft. Driven shaft has to hold under the load of the printing rolls. So it is important that the shaft does not fail during working condition. Table 4.3 gives details of material properties for driven shaft.

Considering weight of maximum number of rolls stored, torque transmitted and self weight of the shaft itself load of 40kN and torque of 8,000Nm is applied on the shaft as shown in the loading Figure. Bearing loads are applied at both ends.

By the simulation, as shown in Figure 4.8-4.10 we obtain result that maximum stress induced is 187MPa. Obtained value is below than allowable stress value. So we can say that our design for driven shaft is safe.

Table 4.3: Material properties for Driven Shaft

Properties	Values
Materials	EN8
Modulus of Elasticity	200GPa
Yield strength	280 MPa
Tensile ultimate strength	510 MPa
Mass Density	7845 Kg/m^3
Possion Ratio	0.29

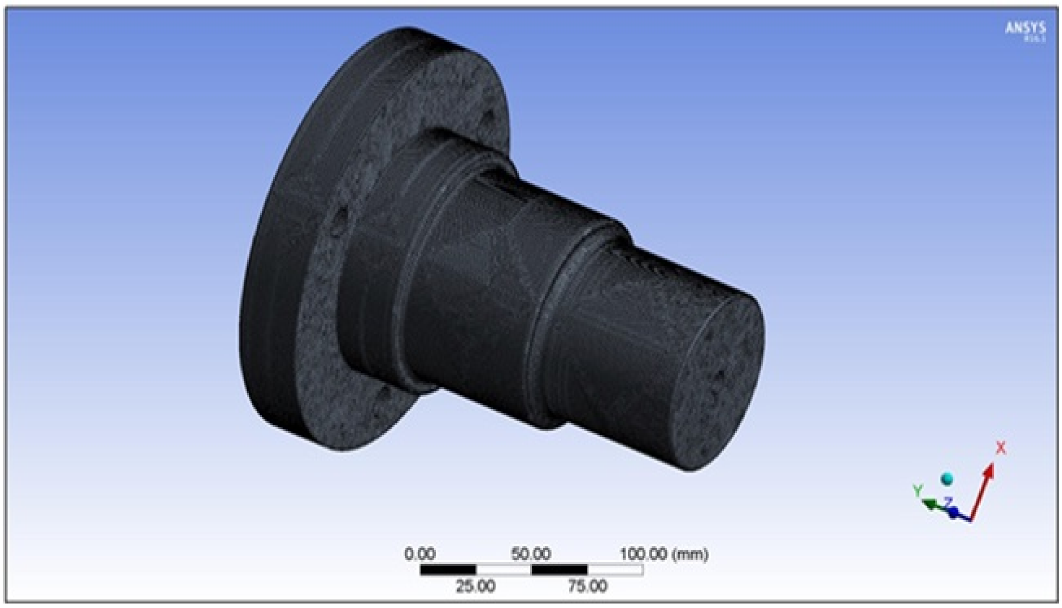


Figure 4.7: Meshed geometry of Driven shaft

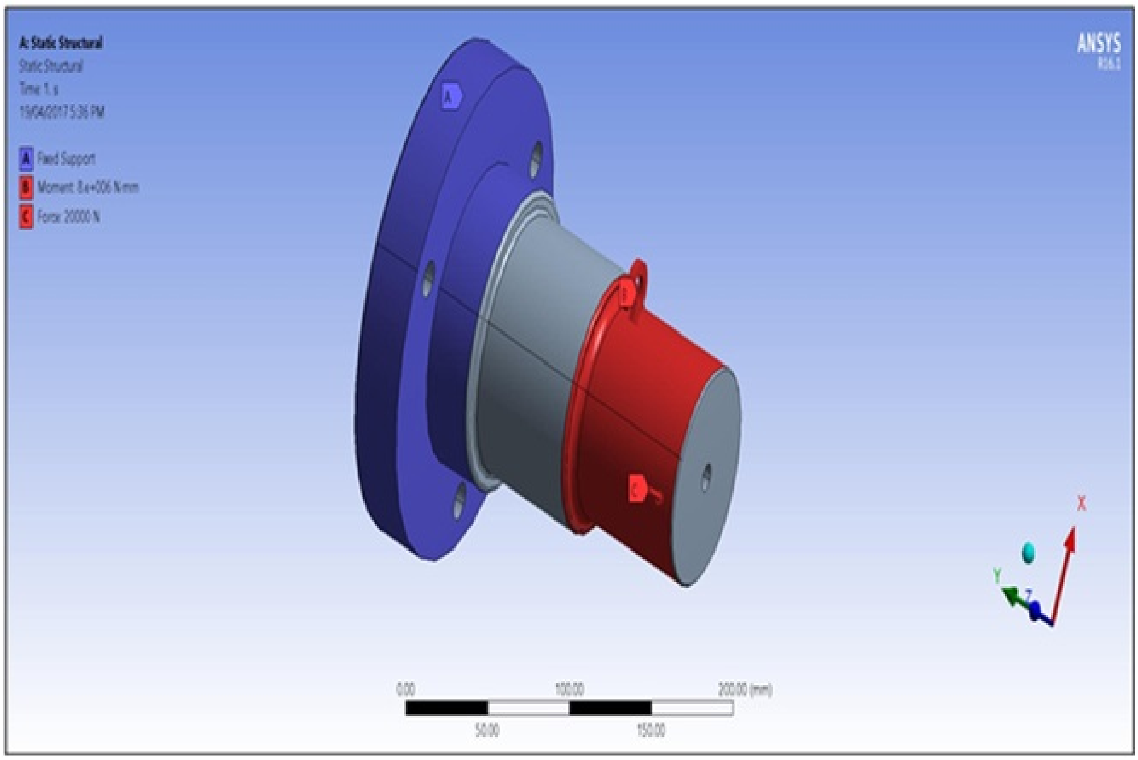


Figure 4.8: Loading condition for Driven shaft

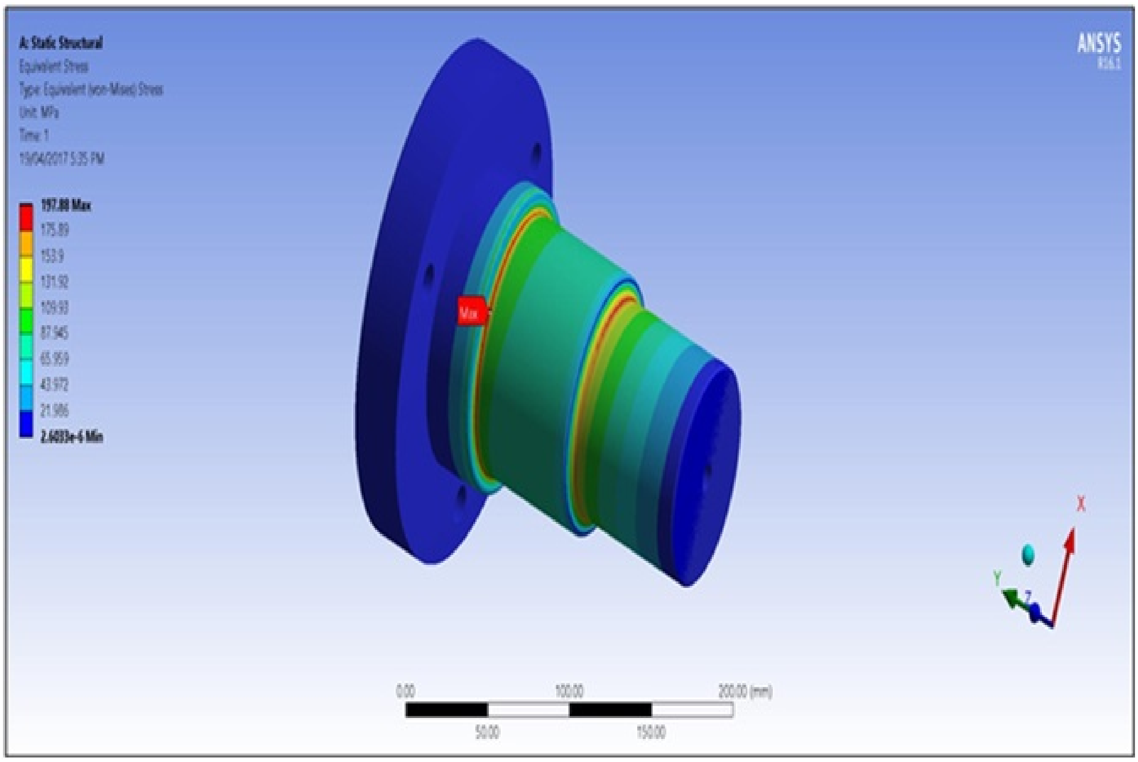


Figure 4.9: Stress induced in Driven shaft

4.4 Hook

Hook or Gripper is the component which remains directly in contact with the printing rolls. Its function is to hold the roll throughout the storage time without dropping it at any instance. Hook is mounted on stoppers which restricts its linear motion but allows free rotary motion. Table 4.4 gives details of material properties for hook.

Considering weight of single roll stored, load of 500N is applied on the hook as shown in the loading Figure. Cylindrical constrain is applied at the eye of the hook as radial and sliding motion are allowed in the hook.

By the simulation, as shown in Figure 4.11-4.13, we obtain result that maximum stress induced is 45MPa. Obtained value is below than allowable stress value. So we can say that our design for hook is safe.

Table 4.4: Material properties for Hook

Properties	Values
Materials	Mild Steel
Modulus of Elasticity	200GPa
Yield strength	250 MPa
Tensile ultimate strength	450 MPa
Mass Density	7845 Kg/m^3
Possion Ratio	0.29

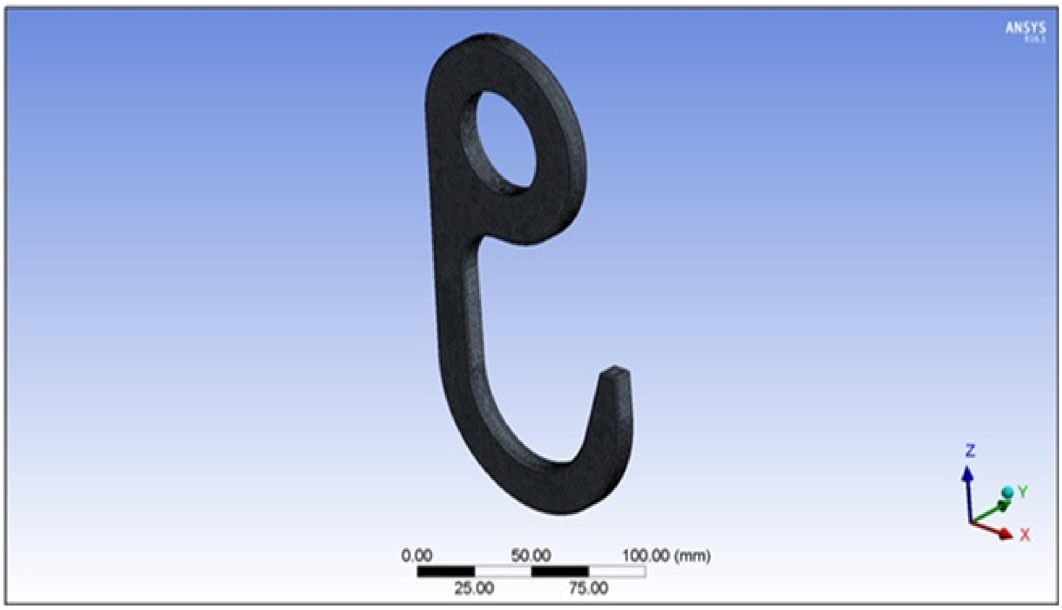


Figure 4.10: Meshed geometry of Hook

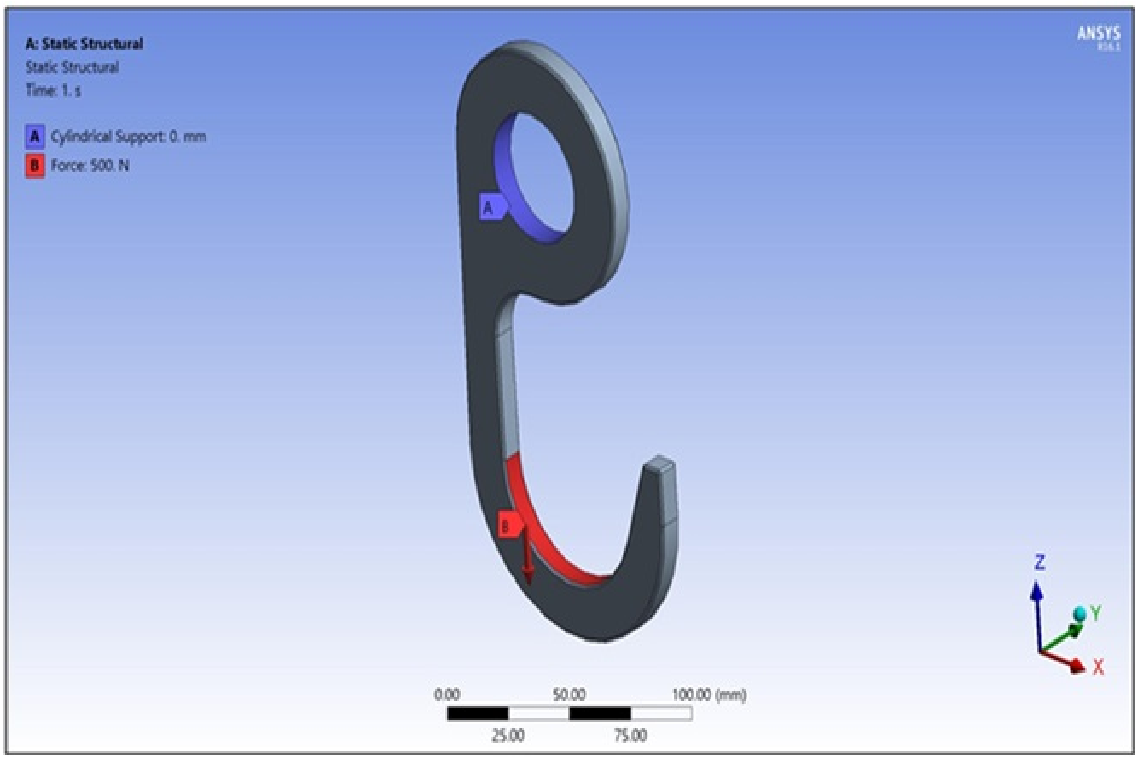


Figure 4.11: Loading condition for Hook

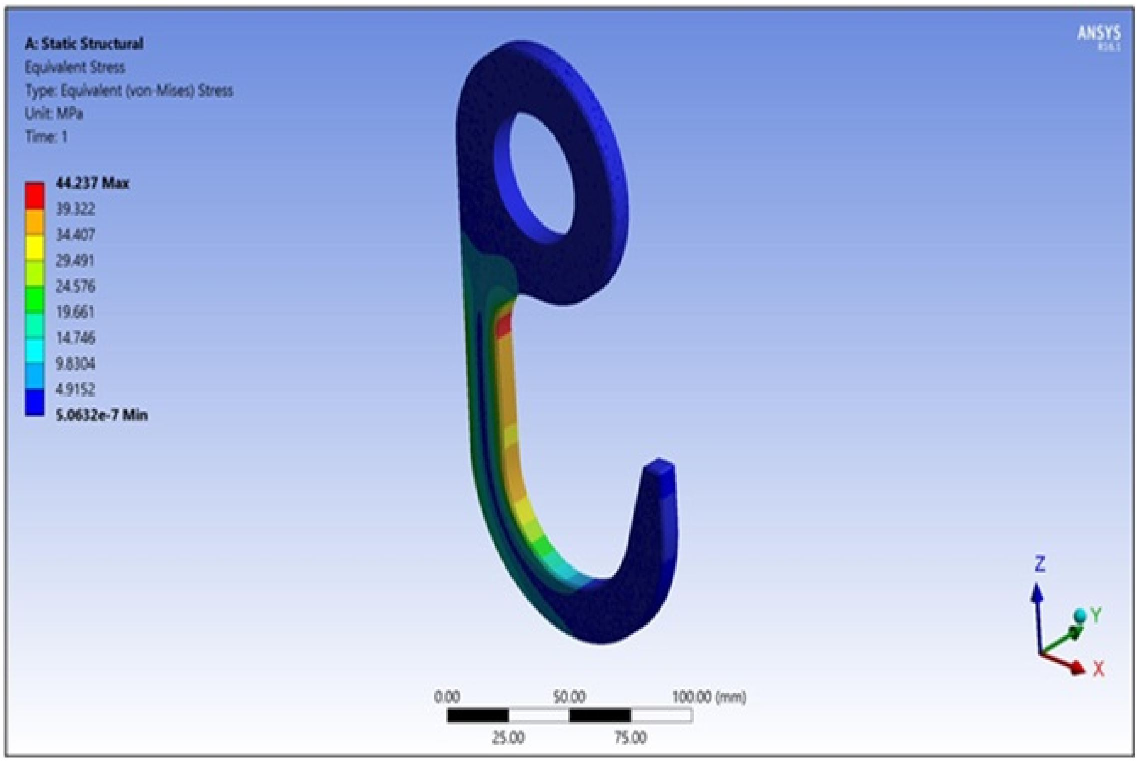


Figure 4.12: Stress induced in Hook

4.5 Rod

Rod is cylindrical component, which join chains on both sides. Distributes the load of printing roll equally to both chains. Hooks are mounted on rod to hold the printing roll. Table 4.5 gives details of material properties for rod.

Considering weight of single roll stored, load of 500N is applied on the rod as shown in the loading Figure. Both ends of the rod are fixed constrained as they are mounted on chains on both sides.

By the simulation, as shown in Figure 4.14-4.16, we obtain result that maximum stress induced is 114MPa value is below than allowable stress value. So we can say that our design for rod is safe.

Table 4.5: Material properties for Rod

Properties	Values
Materials	Mild Steel
Modulus of Elasticity	200GPa
Yield strength	250 MPa
Tensile ultimate strength	450 MPa
Mass Density	7845 Kg/m^3
Possion Ratio	0.29

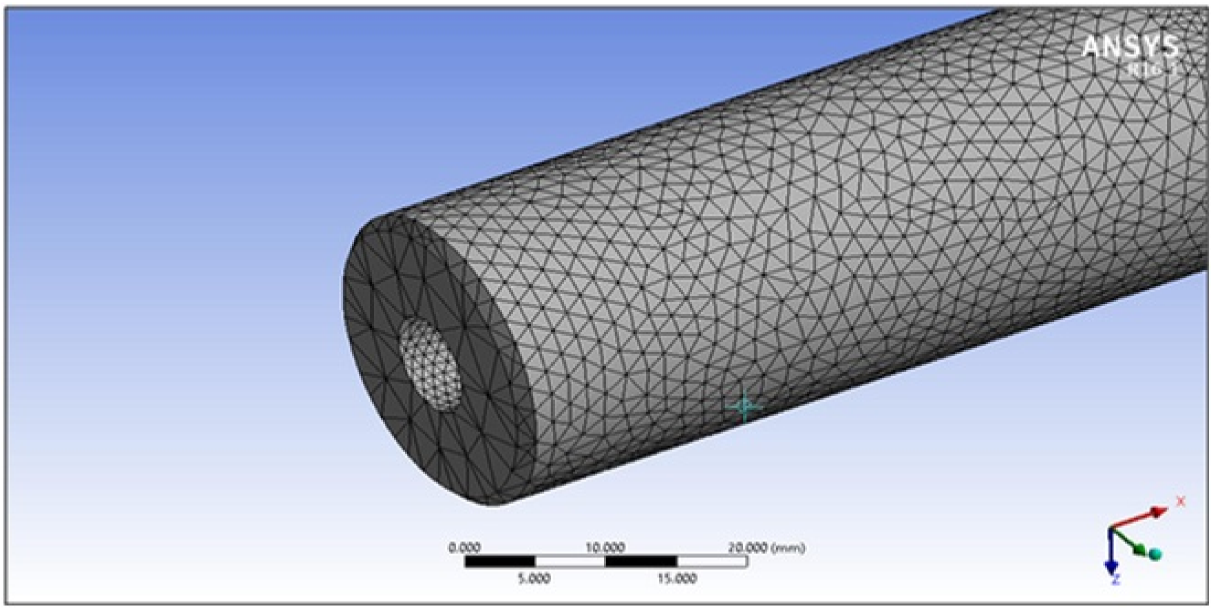


Figure 4.13: Meshed geometry of Rod

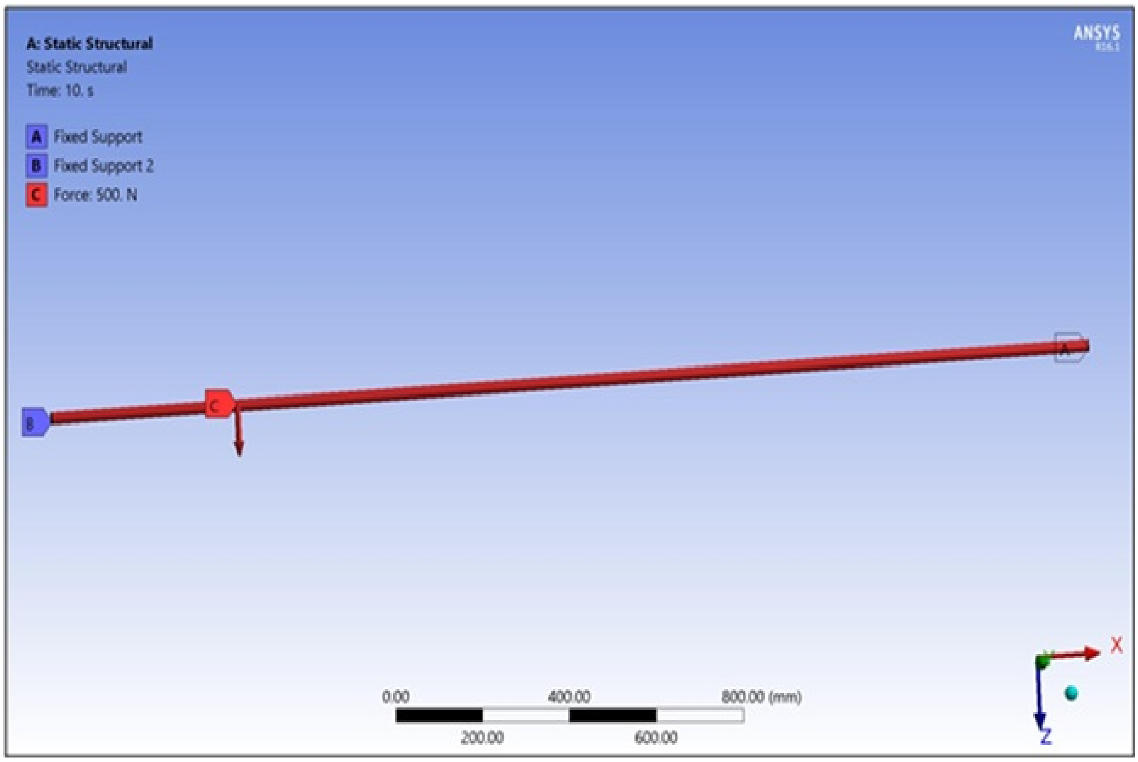


Figure 4.14: Loading condition for Rod

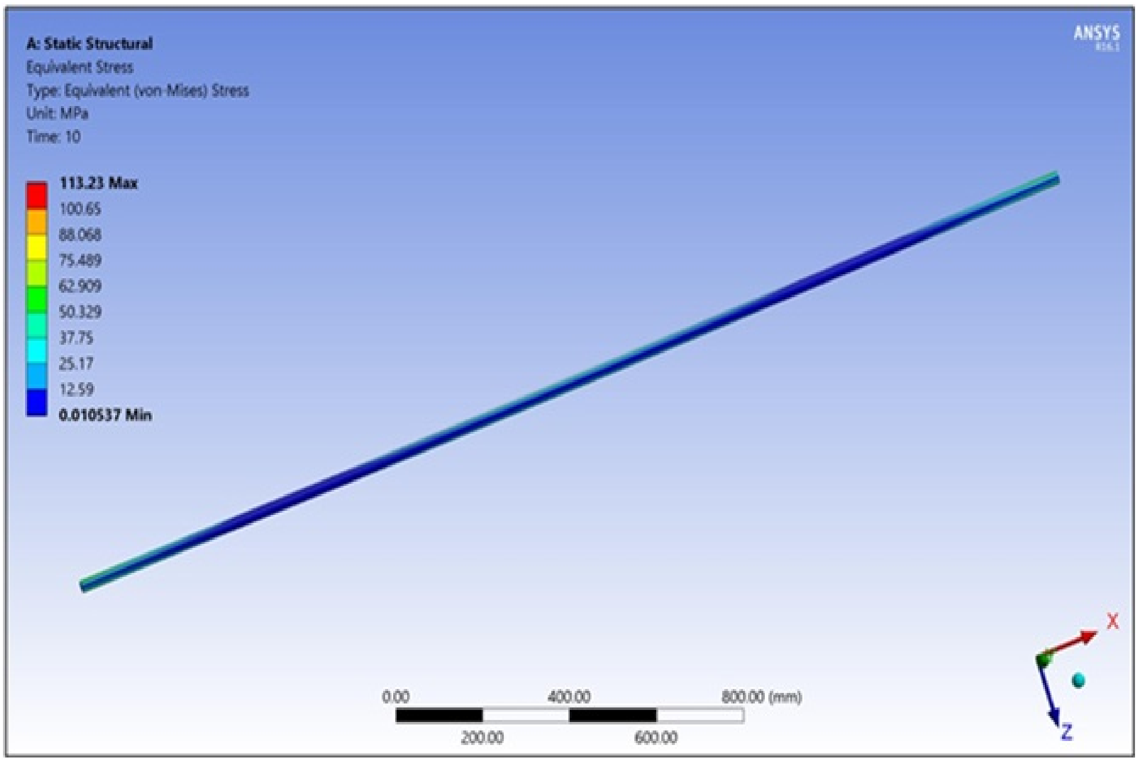


Figure 4.15: Stress induced in Rod

Chapter 5

Conclusion and Future Scope

5.1 Conclusion

In this study, an Automatic Vertical Storage System is conceptualized and designed for the storage of various size of the printing rolls. Assembly drawings and exploded views of different assemblies & sub-assemblies are also created for the Automatic Vertical Storage System. Analytical calculations for the critical parts and load calculation for motor and chain selection is carried out. Further, Finite Element Analysis (FEA) simulation under static loading condition for critical parts of the system such as frame (structure), driver & driven shaft, hook and rod is carried out. Results of the analysis demonstrate that designed parts are safe under the static loading conditions.

5.2 Future Scope

In this study, the analysis of vertical storage system under static loading is carried out. However, the analysis of system under dynamic loading conditions can be a scope of the future. Here, a conceptual model is presented, one can fabricate a prototype according to the model presented and same can be tested for the industrial use. Further, program (code) for automation can be developed for the vertical storage system.

Bibliography

[1] Roodbergen, K. J., & Vis, I. F. A. "A survey of literature on automated storage and retrieval systems. European Journal of Operational Research." 194(2), pp. 343–362, (2009).

[2] David T. Buley, Kenneth Knott , "Designing vertical carousels to maximize operator utilization.", Proceeding Of The 8th Annual Conference On Computers and Industrial Engineering.

[3] Ghomri, L., & Sari, Z. "Mathematical modeling of retrieval travel time for flow-rack automated storage and retrieval systems." IFAC Proceedings Volumes (IFAC-Papers Online), 48(3), pp. 1906–1911, (2015).

[4] Tokola, H., and Niemi, E. "Avoiding fragmentation in mini load automated storage and retrieval systems." IFAC Proceedings Volumes (IFAC-PapersOnline), 48(3), pp. 1973–1977, (2015).

[5] Daniyan, I., Adeodu, O., and Dada, O. M. "Design of a Material Handling Equipment: Belt Conveyor System for Crushed Limestone Using 3 roll Idlers." Journal of advancement in design of a Material Handling Equipment, 1–7,(2014).

[6] Raghvendra Singh gurjar, Arvind yadav, Pratesh jayaswal. "Failure analysis of belt conveyor system in a thermal power plant." ISSN no: 2250 -3536 Volume 2, Issue 3, pp. 204-207, May 2012.

[7] Brezovnik, S., Gotlih, J., Balič, J., Gotlih, K., and Brezočnik, M. "Optimization of an automated storage and retrieval systems by swarm intelligence." Procedia Engineering, 100(January), pp. 1309–1318. (2015)

[8] Jörg Oser, Christian Landschützer, TU Grazm, Austria. "Drive and motion design in material handling equipment."

[9] Hu, Y.-H., Huang, S. Y., Chen, C., Hsu, W.-J., Toh, A. C., Loh, C. K., and Song, T. "Travel time analysis of a new automated storage and retrieval system." Computers & Operations Research, 32(6), pp. 1515–1544, (2005).

[10] Ekren, B. Y., Sari, Z., and Lerher, T. "Warehouse design under class-based storage policy of shuttle-based storage and retrieval system." IFAC Proceedings Volumes (IFAC-PapersOnline), 48(3), pp. 1152–1154, (2015).

[11] Shie-Gheun Koh, Hyuck-Moo Kwon, Young-Jin Kim. "An analysis of the end-of-aisle order picking system : Multi-aisle served by a single order picker." International Journal of production economics, 98, pp. 162–171, (2005).

[12] Young Hae Lee, Moon Hwan Lee, Sun Hur. "Optimal design of rack structure with modular cell in AS/RS." International Journal of production economics, 98, pp. 172–178, (2005).

[13] Anath, K. N. and Rakesh, V. "Design and Selecting Proper Conveyor Belt. Int. Journal of Advanced Technology." Vol. 4(2) pp. 43-49, (2013).

[14] Danielle J. Nativ , Andrea Cataldo, Riccardo Scattolini and Bart De Schutter. "Model Predictive Control of an Automated Storage/Retrieval System." IFAC-PapersOnLine 49-12, pp. 1335–1340, (2016).