1. INTRODUCTION

The vertical lift conveyor is created based on the typical design used in the industries. However, unlike the industry lift conveyor, several requirements need to be followed as the workload is much lighter than the industry lift conveyor.

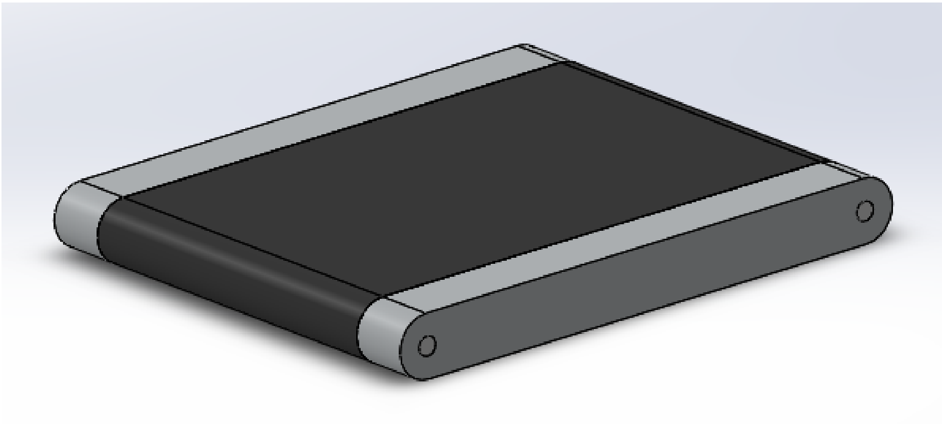

Figure 1: Appearance of the Internal Conveyor Belt on the Platform

The conveyor belt design consists of two metal piece attached at the side of the assembly. There are 2 rollers of radius 23.5 mm fit inside the assembly, in order to transport the item into and out of the platform. The conveyor belt is made of rubber whereas the rollers and the metal pieces are made of aluminium. The platform has a dimension of 40cm x 30cm, which is slightly larger than the design requirement. For the surface area, only the flat side of the conveyor are considered as the item can be transported by the lift properly without falling out of it.

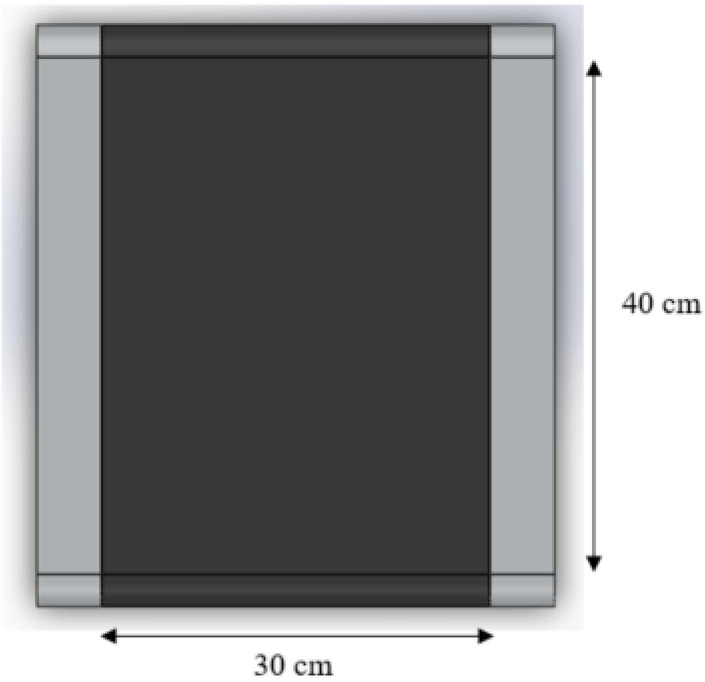

Figure 2: Dimension of the Conveyor Belt

The entire frame has a height of 2.6m, measured from the floor to the top of the frame. The frame has a base sectional area of 50cm x 50cm, which has sufficient space for the platform to be fit properly inside the frame. The lower level of the product line is measured at a height of 30cm, and the top level of the product line is measured at 1.9m. Hence, the lift conveyor has a vertical range movement of 1.6m. The frame of the vertical lift conveyor is made of square metal tube of dimension 30cm x 30cm cross-sectional area.

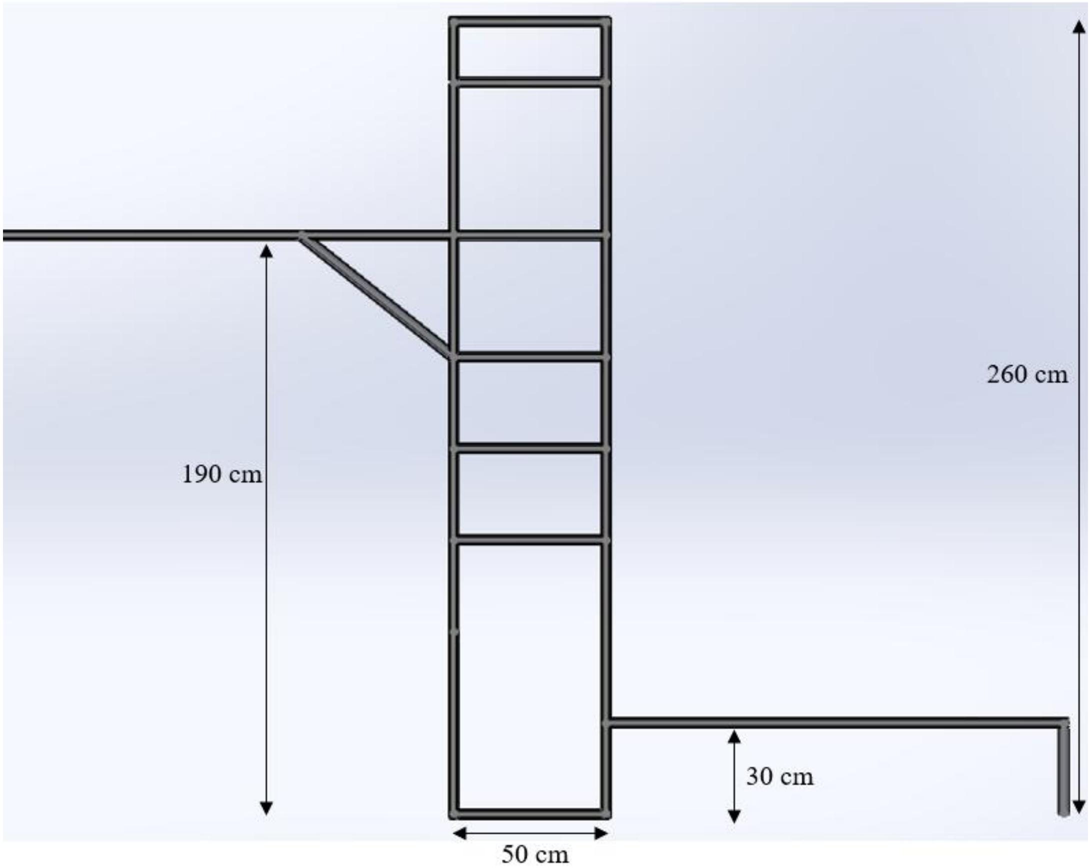

Figure 3: Dimension of the Outer Frame

2. LITERATURE REVIEW

2.1 Reciprocating Vertical Conveyor

Reciprocating Vertical Conveyor (RVC) is an elevator-like vertical transport system which transports goods from a level to another, it is able to transport goods to higher floor levels. To design a RVC, the main parts and components include a carriage, a guide column, and a hydraulic system in the form of either mechanical or hydraulic. For safety reason, RVC is usually enclosed by gates from 3 sides, in order to ensure safe transportation of the goods from one level to another. RVCs are more commonly found in both indoor and outdoor places, ranging from small warehouse to large factory or manufacturing plant. RVCs are economical in terms of its cost of implementation and maintenance, it is less expensive and more affordable compared to a typical elevator. Additionally, it can be implemented in any customized criteria which suits the customer needs. Typically, RVC are designed with an outer skeleton frame which implements several metal bars welded together (figures below). RVCs are found mostly in transporting luggage, boxes, parcels, totes, pallets and trays where it needs to link various levels together.

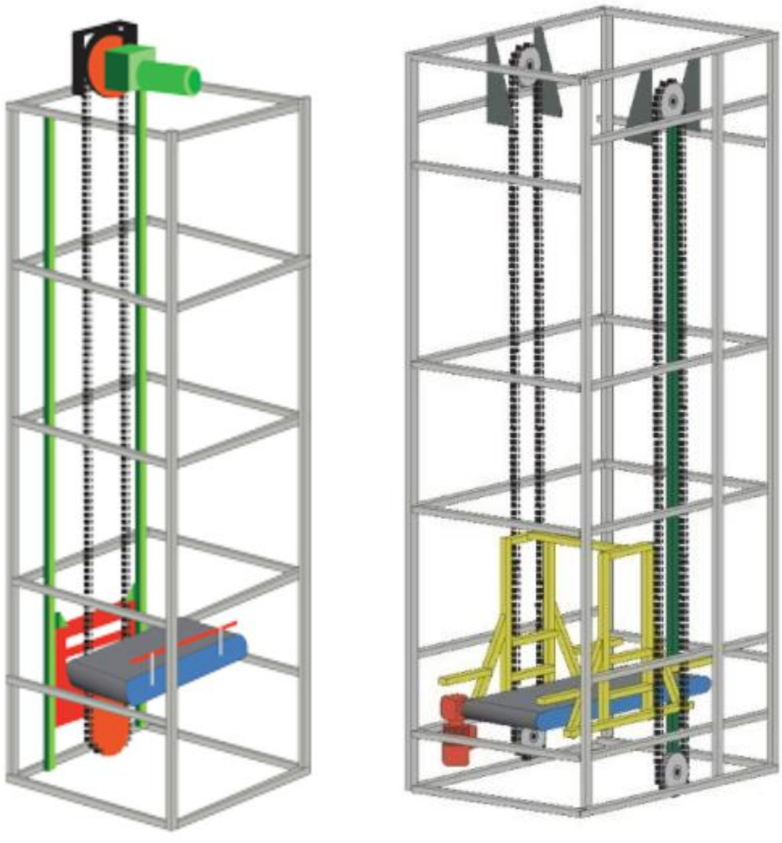

Figure 4: Examples of RVC's Design in Industry usage

According to Nerak Systems, RVC can be categorised into 3 different series based on the maximum load it can withstand and the type of lifting carriage system:

Types	Maximum Load	Type of Lifting Carriage
Lightweight Series	Up to 80 kg	Implements single rubber block chain in an aluminium profile frame.
Medium-duty Series	Up to 300 kg	Suspended from steel-reinforced belts or rubber chains.
Heavy-duty Series	Up to 2.5 tonnes (2500 kg)	

Table 1: Comparison of Different Categories of RVC

2.2 Scissor Lifts

A scissor lift is a type of vertical lifting machine which is made to transport people or equipment. On top of the beam, there is a standing platform surrounding by railing made of beam struts. Scissor lifts are named in such a way because of the way that the supporting metal struts are hinged together, which makes the assembly look like a few sets of connected scissor blades. Those several sets of blade-like assembly appear to be some X-patterns.

Figure 5: Example of Scissor Lift with Roller Conveyor

Scissor lifts are able to move very heavy objects that weigh up to 500 to 100,000 lb, equivalent to more than 45,000 kg. Typically, scissor lifts can lift objects up to a height of 5 to 9 ft. In terms of its base support, some are supported by its base legs, while some can move using 4 wheels placed at the bottom of it.

Figure 6: Parts and Components of a Scissor Lift

Scissor lift moves in vertical direction with its few sets of scissor legs which can raise the platform when they constrict, and lower the platform if they expand in horizontal direction. The figure above shows a hydraulic scissor lift, which use the hydraulic as a power source for the vertical lifting mechanism. A hydraulic lift consists of cylinders which are filled with hydraulic fluid. At the cylinder, there are 2 types of valve which are involved in the lifting function. The down valve is responsible for the reducing of the speed of lowering of the lift by controlling the flow of hydraulic fluid by allowing it to return to its main container. The flow control valve determines the rate at which the hydraulic fluid leaves the cylinder.

In terms of its operation, the main power source is used for the initialisation of the scissor lift. When the power source is turned on, the cylinders are filled with hydraulic fluid. A short while later, the cylinders are full of hydraulic fluid, which is then pushed outwards and causes the scissor legs to move upwards. As a result, the platform is raised. In order to lower down the platform, the hydraulic fluid inside the cylinders need to be released gradually for the platform to be lowered.

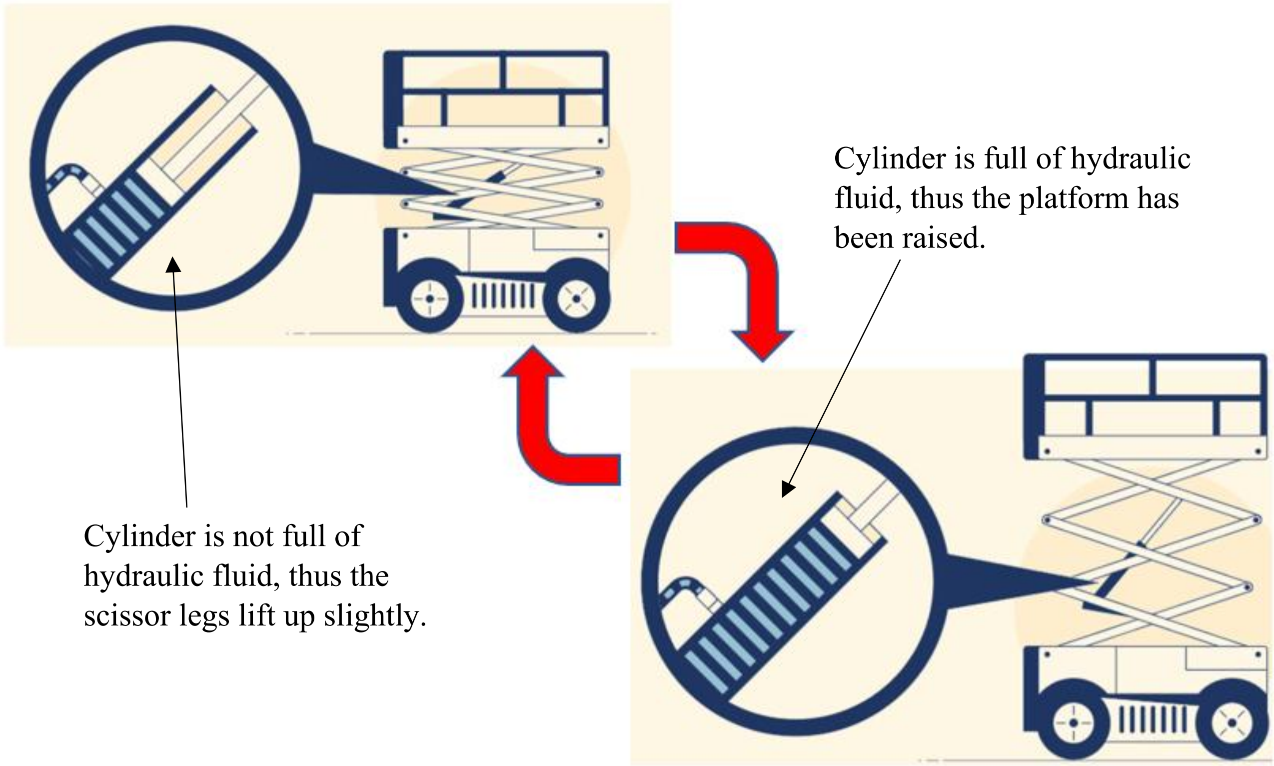

Figure 7: Lifting Mechanism of a Hydraulic Scissor Lift

Besides hydraulic type scissor lift, it can work based on these methods below:

- **Pneumatic**
  Instead of using hydraulic fluid, it uses compressed air to do the lifting and lowering. This type of scissor lift is more suitable to be used in indoor places and for smaller-sized projects.

- **Diesel**
  Able to carry heavier weights, this type of scissor lift is powered using diesel fuel. Due to the fact that it emits gases and it produce higher level of noise, it is usually used in outdoor sites.

- **Electric**
  In contrast to the diesel-powered scissor lift, its lifting mechanism is noiseless and do not emit fumes or gases. In terms of its size, it is smaller and less bulky, which makes it very suitable to be used in tightly packed space.

2.3 Continuous Vertical Conveyor

Continuous vertical conveyor is another type of vertical lifting conveyor which transports items to multiple levels in continuous lifting operation. Unlike Reciprocal Vertical Conveyor which can transport one item at the same time, continuous vertical conveyor can transport multiple items one by one to other levels. It consists of multiple dynamic platforms which transport items up a vertical shaft mechanically. Upon reaching its level point, the platforms will be returned back onto another horizontal conveyor belt.

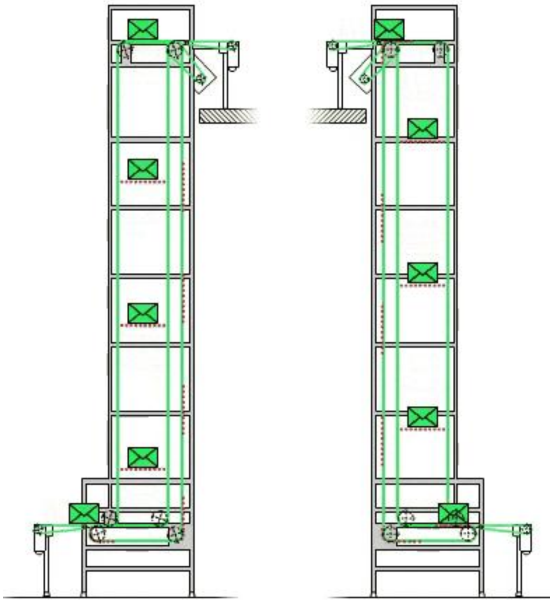

Figure 8: Side View of a Typical Continuous Vertical Conveyor

Compared to other vertical lift conveyors such as reciprocating vertical conveyor, continuous vertical conveyor transports items at a much faster rate, up to 60 items per minutes, which is 1 item per second. It can also save space by implementing either a C or Z-shape configuration. For C-shaped conveyor, both external conveyors outside the frame are at the same side, whereas a Z-shaped conveyor will have the external conveyors at different sides.

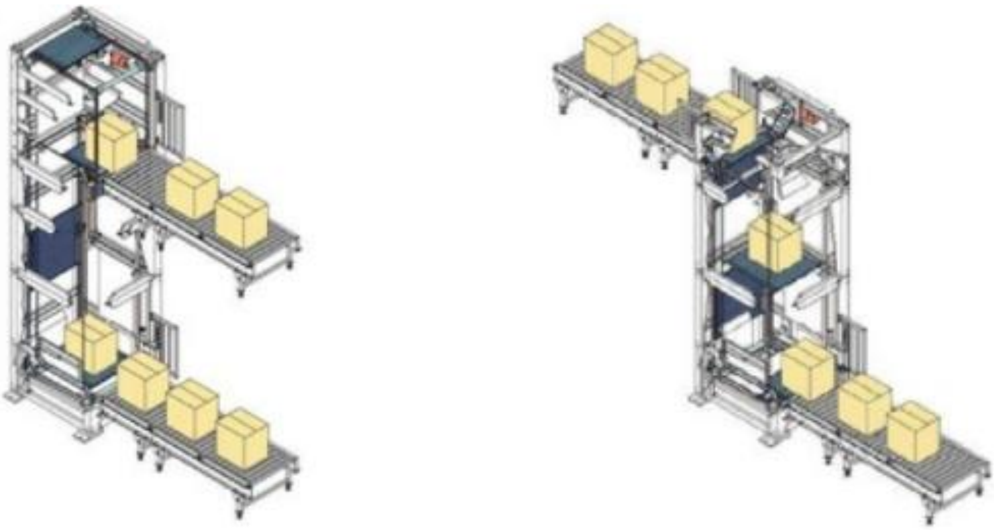

Figure 9: C-shaped Configuration (left) and Z-shaped Configuration (right)

2.4 Spiral Conveyor

Also known as spiral elevator, spiral conveyors are lift conveyors which transport items from one point to another in the form of helix motion. Despite the velocity is in vertical form, the items are transported up by the spiral conveyor belts. Same as continuous vertical conveyor, spiral conveyors allow items to be smoothly transported from one point to another without interfering the flow of the conveying. However, compared to linear conveyor system, spiral conveyors can further save more spaces. This is because linear conveyor involves relatively longer lengths between stations. Spiral conveyors are capable of transporting more items per minute than continuous vertical conveyor due to its longer conveyor paths. In terms of the working mechanism, spiral conveyors consist of a moving belt which revolves around its central column.

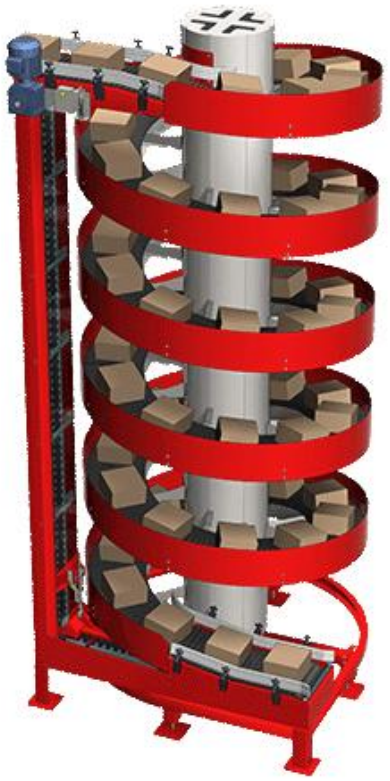

Figure 10: Example of Spiral Conveyor used in the Industry

2.5 Comparison of Different Types of Different Vertical Conveyor System

Types of Vertical Conveyor System	**Reciprocating Vertical Conveyor (RVC)**	**Scissor Lifts**	**Continuous Vertical Conveyor**	**Spiral Conveyor**
Advantages	• Able to handle heavy weight. • Customizable based on customer requirement. • Cheaper and economical. • Simpler internal design.	• Can be moved from one place to another. • Safer • Does not take up much space.	• Fast transporting mechanism, up to 60 items per minute. • Does not occupy much spaces.	• Requires less space • Continuous transport of items. • Cost saving due to the use of only single drive.
Drawback	• It only can transport one item per trip, which is relatively slow compared to the continuous vertical conveyor.	• Slow transport speed, which is not suitable for items where mass producing is needed.	• More complex internal configuration due to the use of multiple shafts, pulleys and chains.	• Not suitable for handling products such as liquid bottle with no cover, as the liquid may spill when going down the conveyor.

Table 2: Advantages and Disadvantages of Different Types of Vertical Conveyor Systems

From the comparison above, due to the design requirements mentioned previously, scissor lifts and spiral conveyor are not suitable to be implemented. Since the minimum travel speed is 300 mm/s, reciprocating vertical conveyor and continuous vertical conveyor are the only 2 types of conveyor which can fulfil this requirement more easily. With the appropriate DC motors and sensors being chosen, both implementations can able to lift up an object vertically with the required maximum weight of 3kg. Both of these types of systems can save much spaces as well, and they can handle heavy weight. However, continuous vertical conveyor requires more components to be built, based on the literature review being done above. As a result, reciprocating vertical conveyor is chosen as the type of vertical lift conveyor to be implemented based on the design requirements mentioned.

3. MECHANISMS DESIGN

3.1 Outer Frame of the System (External Section)

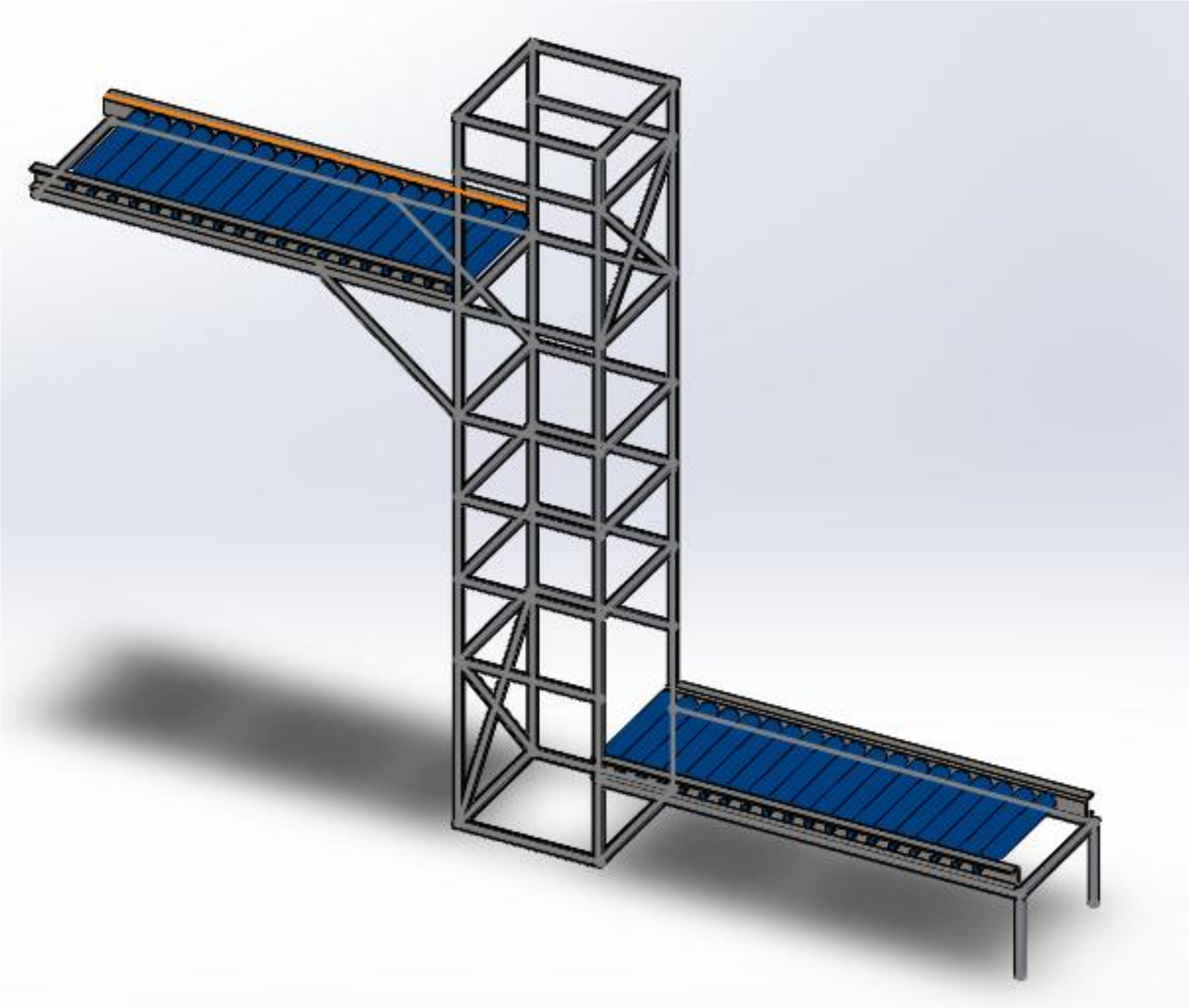

Figure 11: External Skeleton Frame of the System consisting of 2 conveyors

The entire frame has a height of 2.4 m which is measured from the ground to the top, 2 different conveyors are installed at height of 0.3 m for the bottom part and 1.9 m. The difference between these 2 heights is 1.9 – 0.3 = 1.6 m, implying that the system has a vertical moving range of 1.6 m. For the bottom roller conveyor, it has a height of 0.3 m and length of 1.5 m. At the bottom and top of the system, 2 separate X-intersected steel struts are marked as the starting point and ending point of the vertical transport.

3.2 Overall System using 3D Modelling

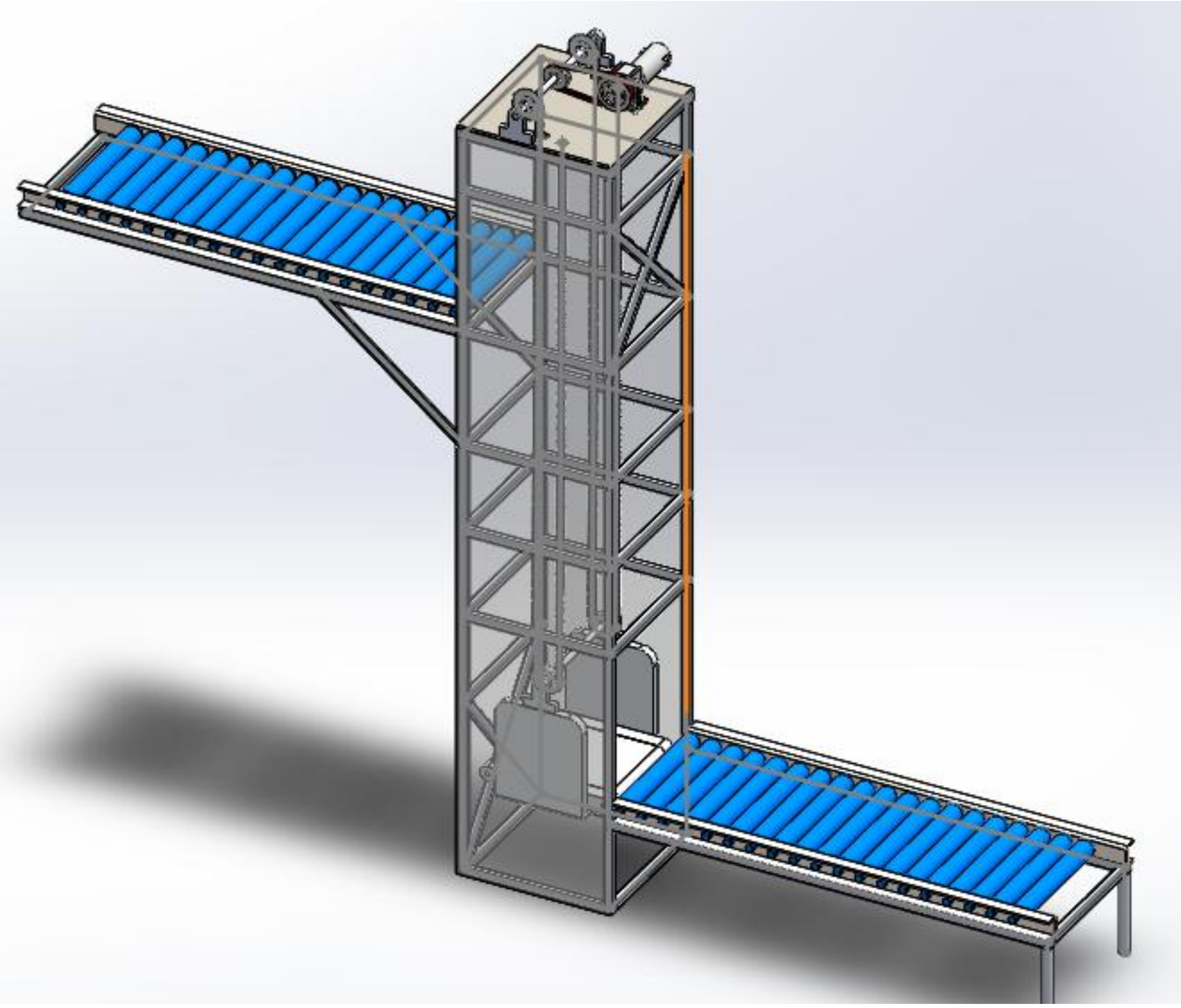

Figure 12: Proposed Design of the Vertical Lift Conveyor (with DC Motor)

The proposed design implements a belt drive system and double cable pulley system which lifts the platform up. When the DC motor rotates, it causes the belt drive to rotate which in turn causing the two pulley to rotate. At the cable pulley section, one end is fixed to the ceiling of the frame whilst another end is attached to the pully on top.

3.3 Components and Parts being used in the 3D Modelling with Explanation

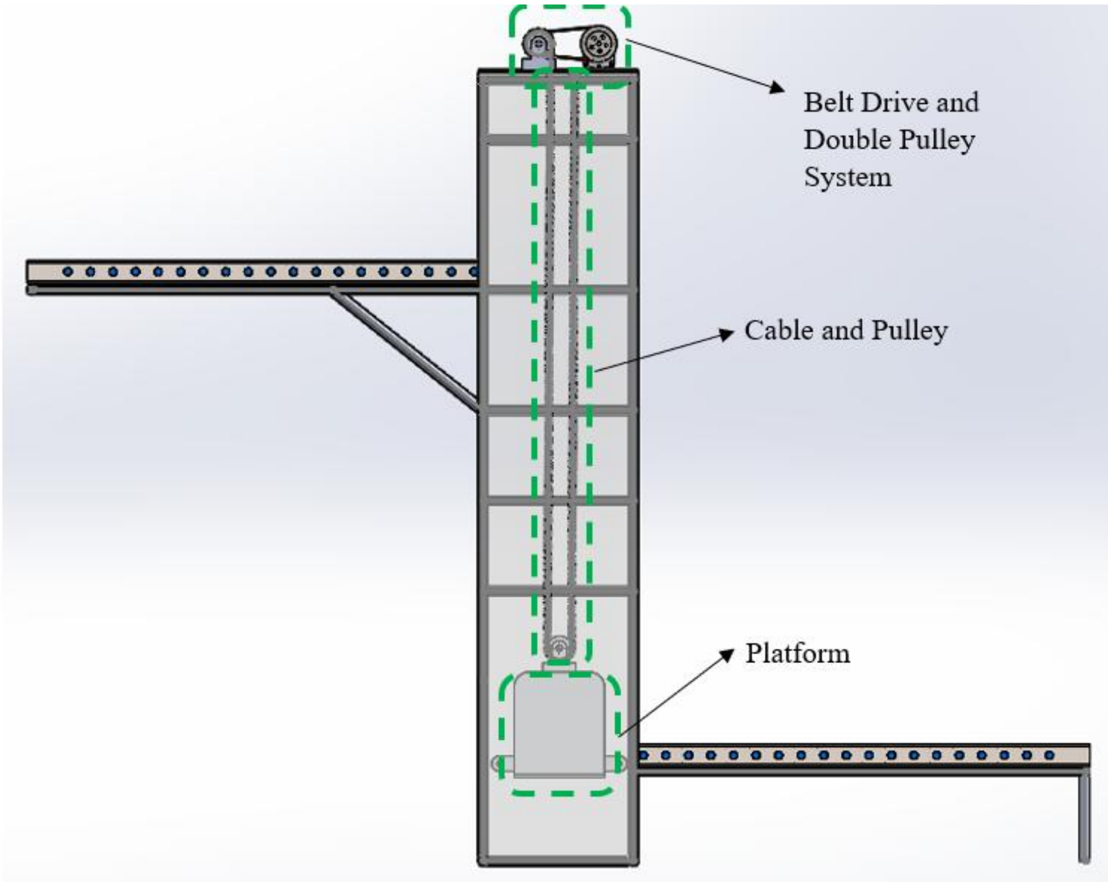

Figure 13: Lifting Mechanism of the Vertical Lift Conveyor using Belt Drive and Two-Sided Pulley System

The vertical lift conveyor consists of 3 parts, namely Belt Drive and Double Pulley System, cable and pulley, and the platform itself.

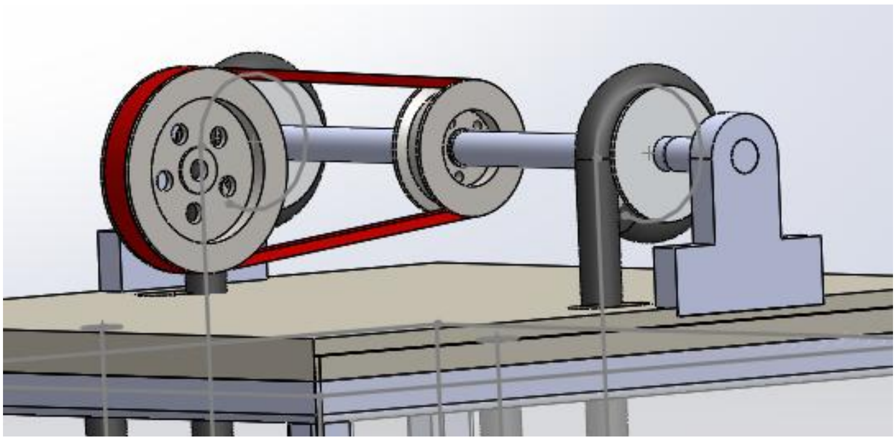

Figure 14: Close-up Look at the Belt Drive and Double Pulley

The belt drive consists of a larger pulley that drives the smaller pulley bearing, the larger pulley of diameter 120 mm is driven by the motor. The smaller pulley which has a diameter of 80 mm is connected to the shaft which has a diameter of 20 mm. When the belt drive rotates, it causes the cable pulley to rotate, which in turn raises/lowers the platform from level to level.

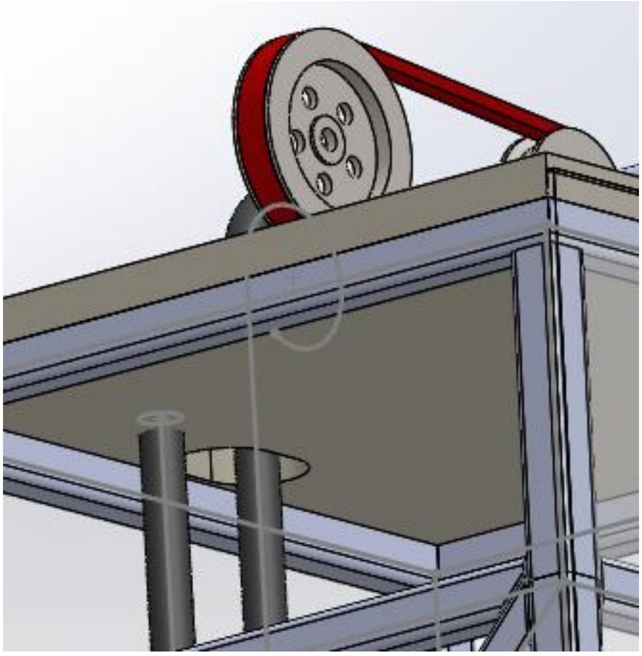

Figure 15: Cable Setup below the Belt Drive and Pulley System

Below the belt drive and pulley system, one of the end of the cable is fixed whereas the other end passes through the extruded cut hole. When the pulley rotates which is caused by the motor rotation, both pulleys will lift the platform up.

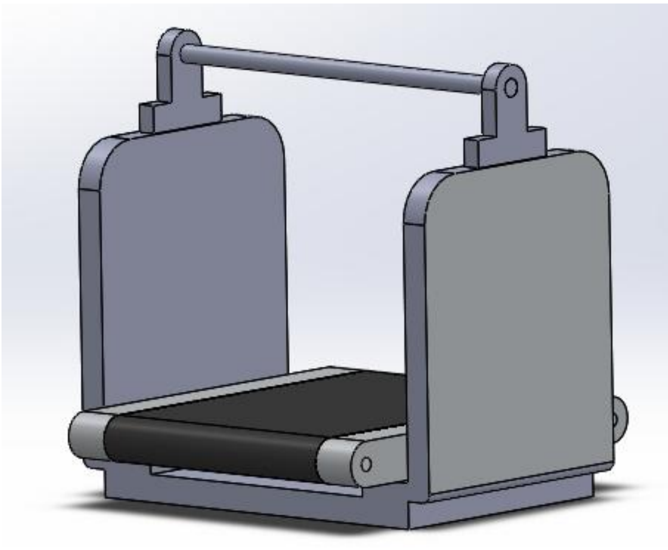

Figure 16: Platform in Isometric View

The platform consists of a pair of shaft supports, a shaft of diameter 20 mm, conveyor clamp and the conveyor belt itself. Another pair of pulley will be attached on each side of the platform for the lifting purpose.

4. SELECTION OF DC MOTOR

Assume that there is a small friction of 10 N acting at the pulleys, and the weight of the platform including the pulleys is 14.95 kg. Assume that the weight of the item being lifted is 3kg maximum.

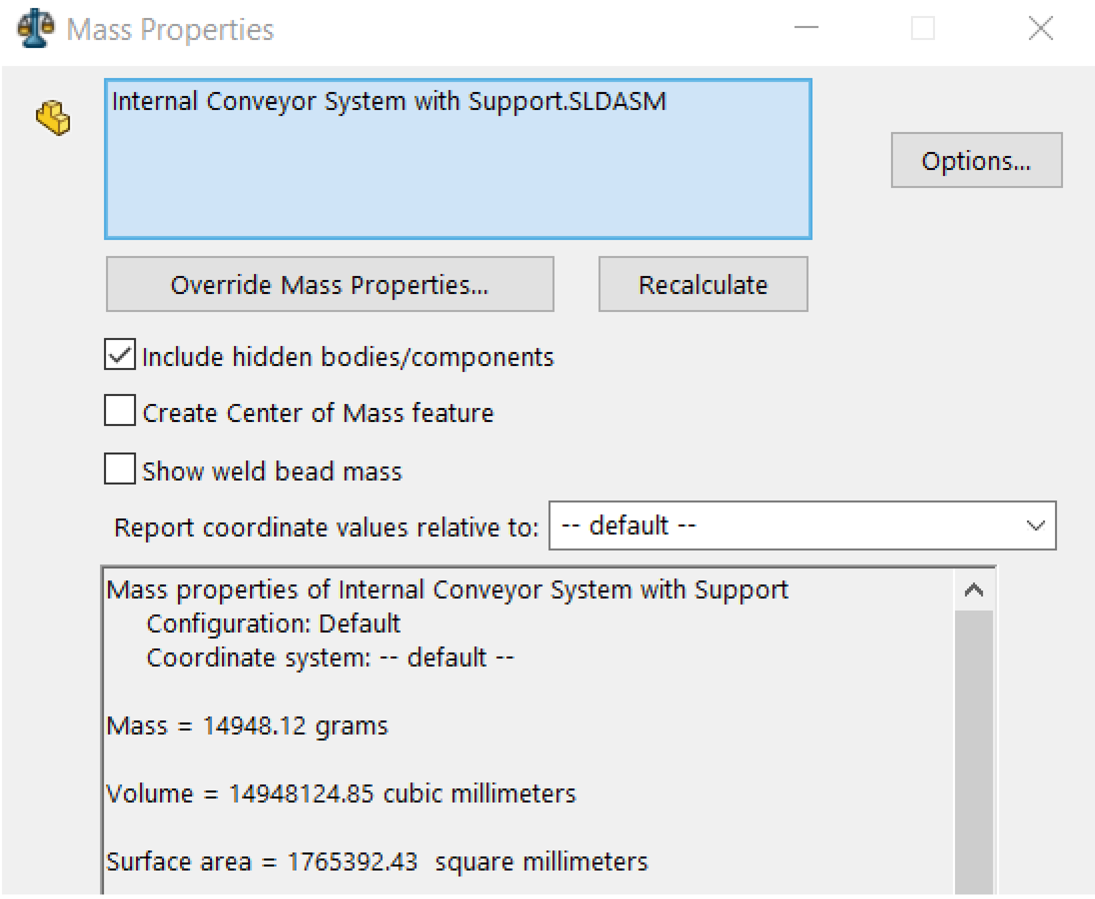

Figure 17: Mass Properties of the Internal Conveyor System

The velocity is set at 0.3 m/s, by using the power formula:

$$P = Fv = (mg + F_{frictional})v = [9.81(14.95 + 3) + 10] \times 0.3$$

$$P = 55.83\ W$$

The torque required can be illustrated as below:

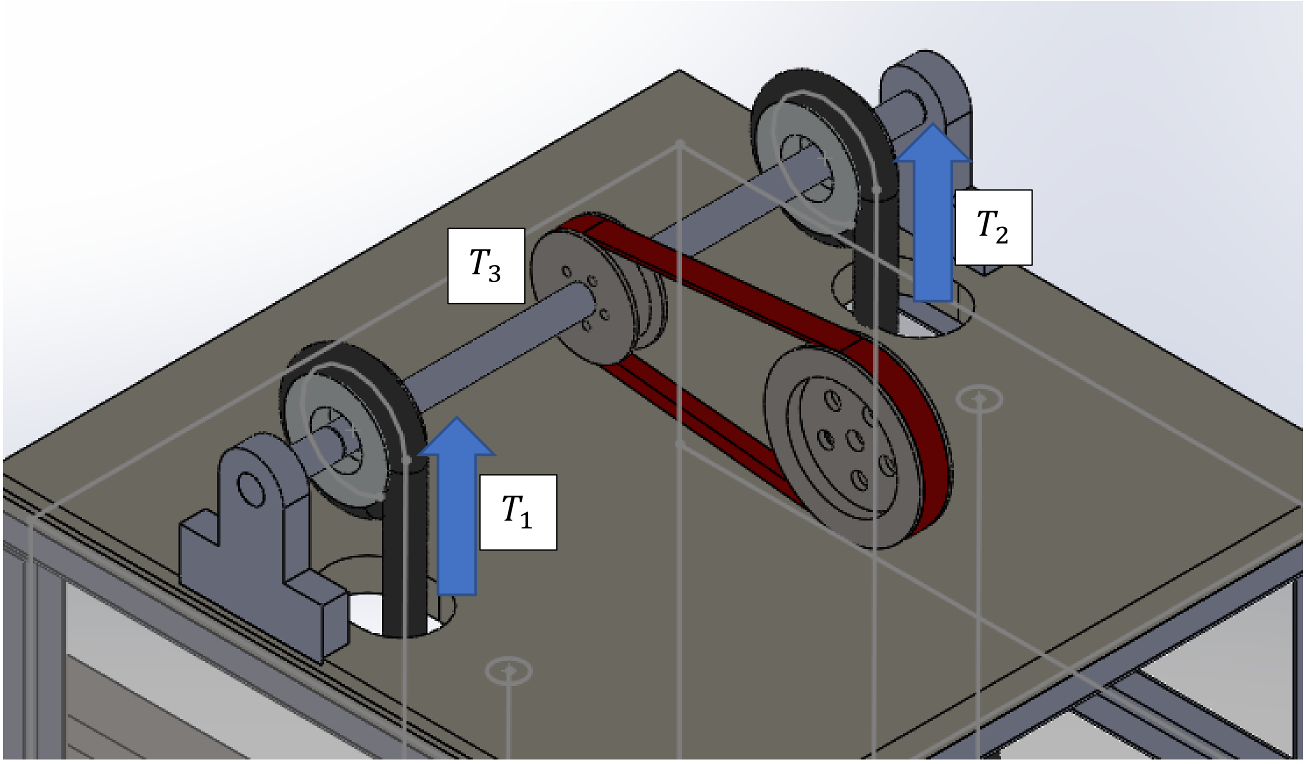

Figure 18: Torque at each Pulley

Each pulley at both sides carry an evenly distributed weight of the platform. Hence the torque developed at the small pully at the belt drive is:

$$T_3 = r \times F = 0.04m \times [9.81(14.95 + 3) + 10] = 7.44\ Nm$$

Based on the torque for the belt drive:

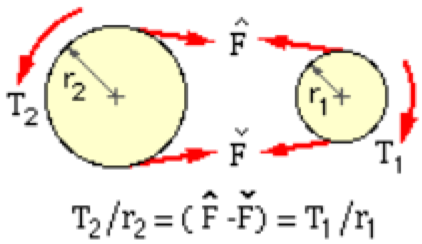

Figure 19: Torque Formula

The torque developed at the larger pulley, T_4 is

$$T_4 = \left(\frac{T_1}{r_1}\right) r_2 = \frac{7.44}{0.04} \times 0.06$$

$$= 11.16\ Nm$$

Hence, the required torque is found to be **11.16 Nm**.

The required speed is calculated by considering the minimum travel velocity and the radius of the pulley.

$$rpm = \frac{v}{r} \times \frac{60}{2\pi}$$

$$= \frac{0.3}{0.04} \times \frac{60}{2\pi}$$

$$= 71.62\, rpm$$

$$By\ using\ the\ formula, d_1 n_1 = d_2 n_2$$

$$d_1 = 120mm, n_1 = ?, d_2 = 80mm, n_2 = 71.62\, rpm$$

$$n_1 = \frac{d_2 n_2}{d_1} = \frac{80(71.62)}{120} = 47.74\, rpm$$

Hence, the minimum required speed is 47.74 rpm.

Based on the condition, a motor with a power rating of between 75W and 100 W should be sufficient for this situation. Since the maximum continuous torque is much lower than the required torque. Hence, a gearbox is required for the reduction of torque value.

The motor chosen is DCX 35 L Ø35 mm, Graphite Brushes, ball bearings 80 W,

This DC graphite-brushed motor has a maximum continuous torque of 77.7 mNm and a nominal speed of 7610 rpm and is rated at 80W with nominal voltage of 12V. Also, a gearbox is required to increase the torque.

$$Gear\ Reduction = \frac{Required\ Torque}{Available\ Torque}$$

$$= \frac{11.16}{0.0777} = 143.63$$

The gearbox chosen is Planetary gearhead GPX 22 UP Ø22 mm, 3-stage. It has a reduction ratio of 150:1.

$$Speed_{output} = \frac{Nominal\ Motor\ Speed}{Gear\ Reduction} = \frac{7610}{150} = 50.73\, rpm$$

5. REFERENCES

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