A Design of Automatic Lifted Cabinet for Elderly and Handicapped

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in cooperation with
Abstract

There are 18% Swedish who have passed the retirement age of 65 years. This number is projected to rise to 30% by 2030. According to a recent report, seven times more people are admitted to a hospital after falling down than the traffic incidents. Some falling incidents happened because the elderly people step on an unreliable chair in order to take the plates or glass from the upper cabinet, [2].

After conducting a survey, we found that there are 75% elderly people (60-80 years old) who consider that they are not satisfied with the present design of the cabinet.

We designed a new device which can make the upper cabinet move automatically. The users can take anything from the upper cabinet conveniently. The device will reduce this type of accident from happening.

Keywords:
Automatic lifting system, cabinet, elderly and handicap, falling accident.
Acknowledgements

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Hai An
Junting Qiu
You You
Yizhou Zhang
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<th>Symbols</th>
<th>Meaning</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B$</td>
<td>Gear thickness</td>
<td>[ cm ]</td>
</tr>
<tr>
<td>$D$</td>
<td>Gear diameter</td>
<td>[ cm ]</td>
</tr>
<tr>
<td>$D_o$</td>
<td>Effective diameter</td>
<td>[ mm ]</td>
</tr>
<tr>
<td>$F$</td>
<td>Force on driven shaft</td>
<td>[ N ]</td>
</tr>
<tr>
<td>$F_a$</td>
<td>Practical thrust</td>
<td>[ N ]</td>
</tr>
<tr>
<td>$F_{min}$</td>
<td>Minimum output force of the motor</td>
<td>[ N ]</td>
</tr>
<tr>
<td>$J$</td>
<td>Inertia</td>
<td>[ kgm$^2$ ]</td>
</tr>
<tr>
<td>$J_t$</td>
<td>Motor inertia</td>
<td>[ kgm$^2$ ]</td>
</tr>
<tr>
<td>$J_w$</td>
<td>The inertia of the working drawer</td>
<td>[ kgm$^2$ ]</td>
</tr>
<tr>
<td>$L$</td>
<td>Length of the drawer</td>
<td>[ kgm$^2$ ]</td>
</tr>
<tr>
<td>$M$</td>
<td>Load torque of motor</td>
<td>[ Nm ]</td>
</tr>
<tr>
<td>$M_a$</td>
<td>Accelerating moment</td>
<td>[ Nm ]</td>
</tr>
<tr>
<td>$M_e$</td>
<td>Resultant torque</td>
<td>[ Nm ]</td>
</tr>
<tr>
<td>$M_f$</td>
<td>Friction moment</td>
<td>[ Nm ]</td>
</tr>
<tr>
<td>$M_H$</td>
<td>Horizontal torque</td>
<td>[ Nm ]</td>
</tr>
<tr>
<td>$M_{max}$</td>
<td>Maximum holding torque requirement</td>
<td>[ Nm ]</td>
</tr>
<tr>
<td>$M_s$</td>
<td>Static moment</td>
<td>[ Nm ]</td>
</tr>
<tr>
<td>$M_T$</td>
<td>Total torque on shaft</td>
<td>[ Nm ]</td>
</tr>
<tr>
<td>$M_v$</td>
<td>Vertical torque</td>
<td>[ Nm ]</td>
</tr>
<tr>
<td>$N$</td>
<td>Gravity</td>
<td>[ N ]</td>
</tr>
<tr>
<td>$P$</td>
<td>Power</td>
<td>[ W ]</td>
</tr>
<tr>
<td>$P_T$</td>
<td>Practical Torque</td>
<td>[ Nm ]</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
<td>Unit</td>
</tr>
<tr>
<td>--------</td>
<td>--------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>R</td>
<td>Lead</td>
<td>[ mm ]</td>
</tr>
<tr>
<td>T</td>
<td>Bending moment of shaft</td>
<td>[ Nm ]</td>
</tr>
<tr>
<td>T_E</td>
<td>Output torque of electromotor</td>
<td>[ Nm ]</td>
</tr>
<tr>
<td>T_max</td>
<td>Dynamic permissible torque</td>
<td>[ Nm ]</td>
</tr>
<tr>
<td>V</td>
<td>Sliding velocity</td>
<td>[ m/min ]</td>
</tr>
<tr>
<td>V_max</td>
<td>Maximum linear velocity of gear</td>
<td>[ m/s ]</td>
</tr>
<tr>
<td>W</td>
<td>Material for circular shaft bending section</td>
<td></td>
</tr>
<tr>
<td></td>
<td>coefficient</td>
<td></td>
</tr>
<tr>
<td>d_a</td>
<td>Diameter of drive gear</td>
<td>[ mm ]</td>
</tr>
<tr>
<td>d_n</td>
<td>Diameter of driven gear</td>
<td>[ mm ]</td>
</tr>
<tr>
<td>f</td>
<td>The friction between the rack and platform</td>
<td>[ N ]</td>
</tr>
<tr>
<td>f_s</td>
<td>Safety factor</td>
<td></td>
</tr>
<tr>
<td>f_T</td>
<td>Temperature factor</td>
<td></td>
</tr>
<tr>
<td>g</td>
<td>Gravity acceleration 9.8</td>
<td>[m/s² ]</td>
</tr>
<tr>
<td>i</td>
<td>Gear reduction ratio for motor</td>
<td></td>
</tr>
<tr>
<td>i_n</td>
<td>Drive ratio</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>Length of the shaft</td>
<td>[ mm ]</td>
</tr>
<tr>
<td>n</td>
<td>Revolving speed</td>
<td>[ rpm ]</td>
</tr>
<tr>
<td>p</td>
<td>Contact pressure</td>
<td>[N/mm²]</td>
</tr>
<tr>
<td>r</td>
<td>Diameter of the small gear</td>
<td>[ mm ]</td>
</tr>
<tr>
<td>s</td>
<td>Pitch</td>
<td>[ m ]</td>
</tr>
<tr>
<td>t</td>
<td>Motor accelerating</td>
<td>[ s ]</td>
</tr>
<tr>
<td>w</td>
<td>Drawer weight</td>
<td>[ kg ]</td>
</tr>
<tr>
<td>z_a</td>
<td>Teeth number of drive gear</td>
<td></td>
</tr>
<tr>
<td>z_n</td>
<td>Teeth number of driven gear</td>
<td></td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
<td>Unit</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Referring factor, here choose 0.3</td>
<td></td>
</tr>
<tr>
<td>$\delta$</td>
<td>Teeth number of driven gear for motor</td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
<td>Efficiency</td>
<td></td>
</tr>
<tr>
<td>$\mu$</td>
<td>Friction factor</td>
<td></td>
</tr>
<tr>
<td>$\sigma_e$</td>
<td>Resultant stress</td>
<td>[ MPa ]</td>
</tr>
<tr>
<td>$\sigma_{-1b}$</td>
<td>Permissible stress</td>
<td>[ MPa ]</td>
</tr>
<tr>
<td>$\varphi$</td>
<td>Stepper angle for motor</td>
<td>[ ° ]</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Angular velocity</td>
<td>[ radians/s ]</td>
</tr>
</tbody>
</table>
Chapter: Introduction

There are 18% Swedish have passed the retirement age of 65 in Sweden. This number is projected to rise to 30% by 2030, [1].

According to a recent report, seven times as many people are admitted to hospital after falling down than the traffic incidents, [2]. In some falling incidents, the elderly people stood on the unreliable chair in order to take items from the upper cabinet.

Figure 1. Over 65 years old people in Sweden,[2].

After we make a survey, we found there are 75% elderly people (60-80 years old) who consider that they are not satisfied with the present design of the cabinet.

If the users can’t take the appliance from the top cabinet, they need to climb ladder or chair. We design a new device which can make the drawers moved automatically horizontally and vertically. The device can reduce this type of accident from happening again.
Chapter: Survey of related work

There are two main designs in cabinets; one of the designs is the ordinary cabinet without complicated structure. This design is the most popular in household. But the elderly people cannot take things from the upper cabinet conveniently. It is one of the reasons that the falling accident happening in apartments.

*Figure 2. The ordinary cabinet, [3].*

In another special design, the whole cabinet can be moved up and down. But the structure of cabinet is very complicated and unreliable. In order to move the whole cabinets, it requires a powerful electric motor.

*Figure 3. The whole cabinet can be moved up and down, [4].*
Chapter 3:
Problem statement, objectives and main contribution

The purpose of this thesis is to design an intelligent cabinet for the elderly people. The device is aimed to help the elderly people take articles conveniently and reduce the rate of the falling accidents due to use of unstable supplies (Chair and ladder etc) for reaching higher shelves.

The main problem is to design a smart structure so that the elderly people can take the objects from the upper cabinet conveniently. We have read a lot of papers and patents and compared them with our design.

Main contribution of this thesis is to design a new structure. The upper cabinet can be moved up and down automatically. We created the model in Autodesk Inventor Professional 2012 and the model is analyzed by using Abaqus, [5], [6].
4 Chapter: Solution

4.1 The proposals for up and down movement

4.1.1 Idea 1 "Pulley"

Rails and ropes are used to implement up and down motions controlled by the stepper motor as shown in Figure 4. The model of this idea has been done in previous project.

Figure 4. The drawer goes up and down through the rails

The stepper motor drives the gear; meanwhile the gear drives the axis which connects the rope and wheel to make the middle drawer up and down according to Figure 4 and Figure 5. When we change the gears as shown in Figure 6, it is the same principle to make the top drawer up and down. So we need two driven shafts to control two drawers.
Since the ropes are unstable in the structure, the iron chains are considered instead of ropes. This proposal has a good carrying ability, but the structure is still very complicated. It is ineffective that one shaft can only drive one drawer.

4.1.2 Idea 2 "Trapezoidal Screw"

Trapezoidal screws are used to implement up and down motion. Every drawer can go up and down through the screw controlled by motor after it comes out from the cabinet as shown in Figure 7.
Figure 7. The drawer goes up and down through the lead screws

The shafts and gears of this proposal are shown in Figure 8. The stepper motor drives the gear; meanwhile the gear drives the axis which connects bevel gears to control the lead screws rotating.

Figure 8. The control system of up and down motions

This structure has a higher cost, but it is simple to implement. Trapezoidal screw has self-locking function, which increase safety and reliability greatly.

4.1.3 Idea 3 "Link mechanism"

This proposal utilizes link mechanism which can control not only up-down but out-in motion. The track in Figure 9 shows the movement of the drawers.

The drawer is attached to one of the pin hole of the outer link. As the circular disk rotates, the front end along with the drawer goes horizontally out and vertically down to make it reachable.

This structure is simple and economic, but not reliable enough since the concentrated force is too big.
4.1.4 Final proposal

Idea 1 has a good carrying ability, but the structure is the most complicated. Idea 2 has a higher cost than idea 3, but it is simple to implement and it is safe and reliable. Idea 3 is the most economical comparing with others, but it is also unsafe as idea 2.

*Table 1. The results of the votes*

<table>
<thead>
<tr>
<th>Property</th>
<th>Pulley</th>
<th>Screw</th>
<th>Link mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economy</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Safety</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Concision</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Reliability</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Carrying</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>
Lead screw is decided to be the final solution after voting.

4.2 The proposals for out and in movement

4.2.1 Idea 1 "Telescopic"

To solve the problem of drawer out and in automatically, first, our group wants to use telescopic structure solving. The telescopic structure consists of many parts. When the motor is working, it can drive the telescopic structure elongate automatically. Conversely, it can make the telescopic structure shrink automatically. When the telescopic structure shrinks, it occupies a small space. With this in mind, we started analyzing the disadvantage of this structure, while seeking better ways to improve.

![Figure 10. The left view of telescopic structure](image)

First, the front and rear of the drawer has a certain height differential as the black arrow shown in Figure 10.

In addition to that, the point of contact of the drawer and telescopic structure is only one as the blue arrow shown in Figure 10. Therefore, the telescopic structure must withstand a greater force, which requires that it is a stronger structure and lags stability.
Third, the structure of the multi-section telescopic is complex; each part of the connection must be very precise.

We also considered using two-section telescopic structure; however, the working efficiency of the two-section telescopic structure is not high, and it looks unsightly.

Finally, we had group discussions to seek ways to solve the disadvantages.

4.2.2 Idea 2 "Mechanical arm"

The mechanical arm is our group came up with the second solution, the mechanical arm can solve the disadvantages of telescopic structure. A mechanical arm composed of two parts, joining the center of the mechanical arm with the bolt connection. The advantage of the mechanical arm is the simple structure and less friction when it works.
The first disadvantage of the mechanical arm is the complexity to make the drawer get in automatically; we want to install a magnet in front of the drawer as the red circle shown in Figure 12, and the drawer can enter automatically by right of the attraction force of the magnet. However, the normal magnetic field strength is small, and the size of the magnetic field strength is difficult to determine. We also considered using electromagnet to solve the problem of magnetic field strength, however, if there are knives or other metal objects in the drawer, they will affect the normal work of the electromagnet and interfere with the metallic objects.

Another disadvantage of the mechanical arm is its instability. Because the center of the mechanical arm is movable, when the drawer moves up and down, meanwhile, the mechanical arm will move. It cannot ensure stable vertical movement of the drawer, hence, the top drawer may touch the below drawer when the top drawer move up and down. We also considered adding two springs at the center of the mechanical arm to control its move, but it will make the structure more complex and when the drawer needs to move inside, the mechanical arm needs more force to drive.
Our design philosophy is a simple structure, ease of control, stable motion and economy.

Because of the unstable motion and problem to control motion stability of the mechanical arm, we have to find ways to solve these disadvantages.

### 4.2.3 Idea 3 "Semi-supported structure"

![Figure 14. Semi-supported structure](image1)

The semi-supported structure is the third proposal that our group want to use, it solves the problem of the drawer's out and in motion. We considered the disadvantages of the previous proposals; hence, the third proposal is necessary to solve these problems.

![Figure 15. The force transfer of semi-supported structure](image2)

Figure 15 shows the drive way of our third proposal, the motor driven gear rotates, and then the force of gear transmitted to rack. The rack is installed on the side of drawer. Hence, when the rack moves, the drawer also moves. The structure semi-supported is simple, and the efficiency is high.
This is the mode of semi-supported structure as shown in Figure 16, the red zone inlay in the platform. The purpose is to prevent movement of the rack from the platform as shown in the circle of Figure 16, and the upper part of the platform can play a supporting role to the rack as the black arrows shown in Figure 16. The upper part of the platform is also the basic for mounting the motor.

The movement of this structure is relatively stable, and easy to control. When the red part of the gear to touch the rod of rack, the gear driven rack movement.

We have also considered using rolling motion instead of sliding motion in the middle of the platform and rack, the work of rolling motion is better than sliding motion. But after calculating, we found the force is very small, it just 8 N. We choose a motor that its minimum force is 8N, so we found the sliding motion is eligible.
Two racks are attached to the two outer bottom side of each drawer as the red part of Figure 18, the movement of the rack controls the movement of the drawer, hence, it can make the out and in movement of the drawer more stable. Meanwhile, the semi-supported structure is relatively simple, relatively strong, precise movement, easy to control. We think it’s a good proposal to solve the problem of the drawer's out and in movement.

4.2.4 Final Proposal

We compared the advantages and disadvantages of three ideas, analyzed the economy, security, reliability, simplicity of the three structures. Semi-supported structure is decided to be the final solution after voting.

Table 2. The results of the votes

<table>
<thead>
<tr>
<th>Proposals</th>
<th>Telescopic structure</th>
<th>Mechanical arm</th>
<th>Semi-supported structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economy</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Safety</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Concision</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Reliability</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Carrying</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>15</td>
<td>18</td>
</tr>
</tbody>
</table>

5= Prefect  
4= Good  
3= Normal  
2= Bad
Chapter: Preliminary Calculation

5.1 The mechanism for up and down movement

5.1.1 Trapezoidal screw

There are almost 20 companies manufacture trapezoidal screws, we choose the THK Company since they have a cheap price screw as 100 yuan in China, [1].

1. Practical Torque $P_T$

We assume that the weight needs to be bear 4 kg per screw. The force diagram on the lead screw is shown as Figure 19.

![Figure 19. Force diagram for lead screw](image)

The practical torque on the lead screw is calculated as:

$$ P_T = PL $$

(1)

where,

- $P$ Force of the load
- $L$ Length of the drawer

$P_T = PL = 39.2 \times 0.433 = 17 N \cdot m$, the practical torque in lead screw is used to choose the type of lead screw.

2. Safety factor $f_s$.

Since the device needs to bear vibrating or striking system, the safety factor should be 4 at least according to THK products guide of trapezoidal screws as shown in Table 3, [9].
Table 3. Safety factor $f_s$

<table>
<thead>
<tr>
<th>Load types</th>
<th>Minimum of $f_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static load</td>
<td>1-2</td>
</tr>
<tr>
<td>Single direction load</td>
<td>2-3</td>
</tr>
<tr>
<td>Vibrating or striking load</td>
<td>4 or more</td>
</tr>
</tbody>
</table>

Temperature factor $f_T=1$, practical torque $P_T=17 \text{ N} \cdot \text{m}$. The safety factor is calculated as:

$$f_s = \frac{f_T \cdot T_{\text{max}}}{P_T} \geq 4 \quad (2)$$

where,

- $f_s$ Safety factor
- $f_T$ Temperature factor
- $T_{\text{max}}$ Dynamic permissible torque

From equation $f_s = \frac{f_T \cdot T_{\text{max}}}{P_T} \geq 4 \quad (2)$, the dynamic permissible torque $T_{\text{max}} \geq 68 \text{ N} \cdot \text{m}$.

According to the torque, THK type DCMB20T is suitable with the dynamic permissible torque 79.4 N·m as shown in Table 4, [10].

Table 4. Parameter of lead screw

<table>
<thead>
<tr>
<th>Change Nut</th>
<th>Outer dimensions</th>
<th>Change nut dimensions</th>
<th>Screw shaft</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCMB 8T</td>
<td>D 15 Tolerance h9 0 Length 16</td>
<td>Flange diameter 28 Diameter 4 H 3.4 B 21 PCD 0.8 r — F — d —</td>
<td>CT 8T</td>
</tr>
<tr>
<td>DCMB 12T</td>
<td>D 20 Tolerance h9 0.1 Length 25</td>
<td>Flange diameter 36 Diameter 5 H 4.5 B 27 PCD 1 r — F — d —</td>
<td>CT 12T</td>
</tr>
<tr>
<td>DCMA 15T</td>
<td>D 22 Tolerance h9 0 Length 15</td>
<td>Flange diameter 44 Diameter 6 H 5.4 B 31 PCD 1.5 r 4.5 F 1.5</td>
<td>CT 15T</td>
</tr>
<tr>
<td>DCMB 15T</td>
<td>D 22 Tolerance h9 0.052 Length 30</td>
<td>Flange diameter 51 Diameter 7 H 6.6 B 38 PCD 1.5 r 4.5 F 1.5</td>
<td>CT 17T</td>
</tr>
<tr>
<td>DCMA 17T</td>
<td>D 28 Tolerance h9 0.052 Length 15</td>
<td>Flange diameter 51 Diameter 7 H 6.6 B 38 PCD 1.5 r 4.5 F 1.5</td>
<td>CT 17T</td>
</tr>
<tr>
<td>DCMB 20T</td>
<td>D 32 Tolerance h9 0 Length 20</td>
<td>Flange diameter 56 Diameter 7 H 6.6 B 42 PCD 1.5 r 6.5 F 2</td>
<td>CT 20T</td>
</tr>
<tr>
<td>DCMB 20T</td>
<td>D 32 Tolerance h9 0 Length 20</td>
<td>Flange diameter 56 Diameter 7 H 6.6 B 42 PCD 1.5 r 6.5 F 2</td>
<td>CT 20T</td>
</tr>
</tbody>
</table>
3. Contact pressure $p$

Lead screw mainly bears torque, so the contact pressure is calculated as:

$$ p = \frac{P_T \times 9.8}{T_{\text{max}}} \quad (3) $$

So the contact pressure is $p = \frac{17 \times 9.8}{79.4} = 2.1 \, N/mm^2$, then the permissible sliding velocity for lead screw can be determined according to Figure 20, [9].

![Figure 20. pV-diagram](image)

4. Sliding velocity $V$. 
From pV-diagram, while the contact pressure is 2.1 N/mm², permissible velocity is 11 m/min. Revolving speed is calculated as:

\[ V = \frac{\sqrt{2} \cdot \pi \cdot D_0 \cdot n}{10^3} \leq 11 \text{ m/min} \]  

(4)

where,

\[ V \] Sliding velocity
\[ D_0 \] Effective diameter
\[ n \] Revolving speed

\( n \leq 132 \text{ rpm} \) is got from the above equation.

Since screw length is 530 mm and the sliding velocity is 11 m/min, the minimum time from the top to the bottom is 3 seconds. Sensors are added in the structure, so that drawer can stop when it is detected by sensors.

5. Safety factor \( f_s \) check.

Temperature factor \( f_T = 1 \), practical torque \( P_T = 17 \text{ N·m} \), dynamic permissible torque \( T = 17 \text{ N·m} \). The safety factor \( f_s = \frac{f_T \cdot T_{\text{max}}}{P_T} = \frac{1 \times 79.4}{17} = 4.6 \), it is safe since \( f_s \) is bigger than 4.

6. Thrust.

While practical torque is 17 N·m and the friction factor is 0.2, the efficiency is 0.67 according to Table 5, [9].

<table>
<thead>
<tr>
<th>Friction factors</th>
<th>0.1</th>
<th>0.15</th>
<th>0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>0.82</td>
<td>0.74</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Practical thrust can be calculated as:

\[ F_a = \frac{2 \cdot \pi \cdot \eta \cdot P_T}{R \cdot 10^{-3}} \]  

(5)

where,

\[ F_a \] Practical thrust
\[ \eta \] Efficiency
\[ F_a = \frac{2 \cdot \pi \cdot \eta \cdot P_T}{R \cdot 10^{-3}} = \frac{2 \cdot \pi \cdot 0.67 \cdot 17}{60 \cdot 10^{-3}} = 1193N \] It is safe since the practical thrust is smaller than permissible value, 8330 N as shown in Table 4.

So DCMB20 + 530LT type shown as Table 4 can be chose for the structure. The pith of it is 6.67 mm.

### 5.1.2 Motor

1. Drive ratio.

\[
\begin{align*}
\frac{i}{d_n} &= \frac{z_n}{d_d} = \frac{z_d}{z_d} \\
&= \frac{4}{5} = \frac{16}{20} = \frac{3}{2} = \frac{1120}{120} = \frac{3}{2} \\
\end{align*}
\]

From Figure 21, there are two spur gears and four bevel gears. The drive ratio is calculated as:

\[
\begin{align*}
\frac{i}{d_n} &= \frac{z_n}{d_d} = \frac{z_d}{z_d} \\
&= \frac{4}{5} = \frac{16}{20} = \frac{3}{2} = \frac{1120}{120} = \frac{3}{2} \\
\end{align*}
\]

From equation (6), we got \[ i_{12} = \frac{d_2}{d_1} = \frac{120}{120} = 1 \]
\[ i_{23} = \frac{d_3}{d_2} = \frac{80}{120} = \frac{2}{3} \]
\[ i_{34} = \frac{z_4}{z_3} = \frac{20}{16} = \frac{5}{4} \]
so that $i_{14} = i_{12} \cdot i_{23} \cdot i_{34} = \frac{2 \times 5}{3 \times 4} = \frac{5}{6} = 0.83$.

While the feed velocity for lead screw is 7.92 m/min, the rotating speed of gear 1 is $n_1 = \frac{S}{i \cdot \pi \cdot d_1} = \frac{7.92}{0.83 \times \pi \times 0.12} = 25 \text{rpm}$, it is also the motor speed requirement. Since the rotating speed is very low, the motor phase inductance and resistance should be high.

2. Pulse.

Primary election motor type is hybrid stepping motor series with 1.8° step angel, 200 steps and 360 degrees per round; We choose subdivided driving as 4 lines; then every step of the motor is $1.8/4 = 0.45°$ through the subdivided driving; $200 \times 4 = 800$ steps per round; so every step should move $\delta = 60/800 = 0.075 \text{ mm}$.


$$i = \frac{(\varphi \cdot s)}{(360 \cdot \delta)} \quad (7)$$

where,

$\varphi$ Stepper angle for motor
$s$ Pitch
$\delta$ Teeth number of driven gear for motor

So the gear reduction ratio is $i = \frac{0.04 \times 6.67}{360 \times 0.075} = 0.01$.

4. Inertia.

The inertia of cylinder is calculated as:

$$J = 0.78D^4B \times 10^{-8} \quad (8)$$

where,

$J$ Inertia
$D$ Gear diameter
$B$ Gear thickness

According to equation

The inertia of cylinder is calculated as:
\[ J = 0.78D^4B \times 10^{-8} \quad (8), \]

Gear 1 & 2: \( J_1 = J_2 = 0.78 \times 12^4 \times 3.3 \times 10^{-8} = 5.3 \times 10^{-4} \text{ (kg \cdot m}^2) \)

Gear 3: \( J_3 = 0.78 \times 8^4 \times 4.5 \times 10^{-8} = 1.4 \times 10^{-4} \text{ (kg \cdot m}^2) \)

Gear 4: \( J_4 = 0.78 \times 10^4 \times 4.5 \times 10^{-8} = 3.5 \times 10^{-4} \text{ (kg \cdot m}^2) \)

Screw: \( J_s = 0.78 \times 1.5^4 \times 53 \times 10^{-8} = 2.09 \times 10^{-6} \text{ (kg \cdot m}^2) \)

The inertia of the working drawer on the lead screw is calculated as:

\[
J_w = \left( \frac{s}{2\pi} \right)^2 \frac{w}{g} \quad (9)
\]

where,

\[
w \quad \text{Drawer weight}
\]

\[
g \quad 9.8 \text{ m/s}^2
\]

Working drawer: \( J_w = \left( \frac{0.667}{2\pi} \right)^2 \times \frac{4}{980} \times 10^{-2} = 4.6 \times 10^{-7} \text{ (kg \cdot m}^2) \)

The motor inertia \( J_t \) is:

\[
J_t = J_1 + J_2 + \frac{J_3}{i_{13}^2} \times 2 + \frac{2}{i_{14}^2} [(J_4 + J_s) + J_w]
\]

\[
= 10.6 \times 10^{-4} + \frac{1.4 \times 10^{-4}}{0.67^2} \times 2 + \frac{2}{0.83^2} (3.5 \times 10^{-4} + 2.09 \times 10^{-6} + 4.6 \times 10^{-7})
\]

\[
= 2.7 \times 10^{-3} \text{ (kg \cdot m}^2)
\]

5. Moment.

The accelerating moment of motor is calculated as:

\[
M_a = \frac{J_t n}{t} \times 1.02 \quad (10)
\]

where,

\[
M_a \quad \text{Accelerating moment}
\]

\[
J_t \quad \text{Motor inertia}
\]
Motor accelerating time

The accelerating moment is \( M_a = \frac{2.7 \times 10^{-3} \times 25}{0.3} \times 1.02 = 0.23 \text{Nm} \).

The friction moment is calculated as:

\[
M_f = \frac{\mu P_s}{2\pi \eta i} \times 10^{-2}
\]  \hspace{1cm} (11)

The friction moment is \( M_f = \frac{0.1 \times 39.2 \times \sin 45^\circ \times 6.67}{2\pi \times 0.8 \times 0.01} \times 10^{-2} = 3.7 \text{Nm} \).

So the load torque \( M \) is \( M = M_a + M_f = 0.23 + 3.7 = 3.93 \text{Nm} \).

The maximum motor holding torque safety ratio should be between 0.2 and 0.4, and the safety ratio is calculated as:

\[
s = \frac{M}{M_{\text{max}}}
\]  \hspace{1cm} (12)

The safety ratio is 0.4. Therefore, the maximum moment is 9.8 Nm. Then the highest rotating velocity is calculated as equation

\[
M_a = \frac{J_n}{t} \times 1.02
\]  \hspace{1cm} (10),

\[
M_{\text{max}} = \frac{0.27 \times n}{0.3} \times 1.02 \times 10^{-2} = 9.8 \text{Nm}
\]

The highest rotating velocity is 1066 rpm, while the maximum holding torque is 9.8 Nm.

So type 85BYGH45C-012 with 11.5 Nm holding torque is chosen for the device.

5.1.3 Shaft

C45E4 steel is chosen as the main material. The method is only applicable to bear the precise calculation of torque of drive shaft and it can also be used for both approximate calculation of the bending moment and the torque axis.

\[
P = \Omega M_s = \frac{2\pi \times 25}{60} \times 10 = 26 \text{W}
\]

where,
To transmit only torque axis with circular cross section, the strength condition is calculated as:

$$\tau = \frac{9.55 \times 10^6 P}{0.2d^3n} \leq \tau_p$$  \hspace{1cm} (13)

where,

- $\tau$ Stress
- $d$ Diameter of the drive shaft

From equation (13),

$$d \geq \sqrt[3]{\frac{9.55 \times 10^6 P}{0.2 \cdot \tau_p \cdot n}} = \sqrt[3]{\frac{9.55 \times 10^6 \times 26 \times 10^{-3}}{0.2 \cdot 40 \cdot 25}} = 10.74\text{mm}$$

For both the torque and the axis of bending moments, this method can be used to estimate the strength of shaft. But it must be the allowable torsion shear stress $\tau_p$ reduced according Table 6 in order to consider the effect of bending moment on the shaft. What we should emphasize more is to use the method to a preliminary estimate the diameter of the shaft. Then we can try to design the structure of shaft.

**Table 6. Material and allowable stress**

<table>
<thead>
<tr>
<th>Material</th>
<th>Q235,20</th>
<th>35</th>
<th>C45E4</th>
<th>40Cr,35SiMn</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_p$ [MPa]</td>
<td>12-20</td>
<td>20-30</td>
<td>30-40</td>
<td>40-52</td>
</tr>
<tr>
<td>C</td>
<td>160-135</td>
<td>135-118</td>
<td>118-107</td>
<td>107-98</td>
</tr>
</tbody>
</table>

Generally, there is a key way, so the $d$ should be increased by 3 - 4%.

$d=10.73 \times (1+3.5\%) = 11.06\text{ mm}$, so the shaft diameter is chosen 12 mm.

A diagram for the calculation of shaft is shown in Figure 22.
Figure 22. Force diagram of the shafts

The force on the shaft is calculated as:

\[ F = \frac{M_s}{d} \]  \hspace{1cm} (14)

where,

- \( F \) is the force on the driven shaft.

So that the force is \( F = 10 / 0.12 = 83 \) N. There are two support points, the force is separated, \( F_3 = F_4 = 41.5 \) N.

While the horizontal torque \( M_H = 0 \), the vertical torque is calculated as:

\[ M_v = Fl \]  \hspace{1cm} (15)

where,

- \( l \) is the length of the shaft
- \( M_v \) is the vertical torque
- \( M_H \) is the horizontal torque

\[ M_v = 83 \times 0.11 = 9.13 \text{Nm} \]

\[ T = \frac{9550P}{n} = \frac{9550 \times 26 \times 10^{-3}}{25} = 10 \text{Nm} \]
Make the H and V on the vertical plane of the bending moment diagram of the $M_H$, $M_V$. The vertical torque and bending moment diagram is shown in Figure 23.

![Figure 23. Bending moment and torque diagram](image)

The equivalent bending moment $M_e$ is calculated as:

$$M_e = \sqrt{M_T^2 + (\alpha T)^2}$$  \hspace{1cm} (16)

where,

- $M_e$: Resultant torque
- $M_T$: Total torque
- $\alpha$: Referring factor, here choose 0.3

$$M_e = \sqrt{9.13^2 + (0.3 \times 10)^2} = 9.6\, N \cdot m$$

The equivalent stress is calculated as:

$$\sigma_e = \frac{M_e}{W} \leq \sigma_{-1b}$$

where,

- $\sigma_e$: Resultant stress
- $W$: Material for circular shaft bending section coefficient
- $\sigma_{-1b}$: Permissible stress

Normally, $W=0.1d^3$, since $d=0.012\, m$, $W$ is $1.73 \times 10^{-7}$. 
So we get $\sigma_e = 56$ MPa, it is safe since it is less than 65MPa as shown in Table 7.


<table>
<thead>
<tr>
<th>Material</th>
<th>$\sigma_b$</th>
<th>$\sigma_{+1b}$</th>
<th>$\sigma_{0b}$</th>
<th>$\sigma_{-1b}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon steel</td>
<td>400</td>
<td>130</td>
<td>70</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>170</td>
<td>75</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>200</td>
<td>95</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>700</td>
<td>230</td>
<td>110</td>
<td>65</td>
</tr>
<tr>
<td>Alloy steel</td>
<td>800</td>
<td>270</td>
<td>130</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>900</td>
<td>300</td>
<td>140</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>330</td>
<td>150</td>
<td>90</td>
</tr>
<tr>
<td>Cast steel</td>
<td>400</td>
<td>100</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>120</td>
<td>70</td>
<td>40</td>
</tr>
</tbody>
</table>

Dangerous section diameter of axle can be calculated as:

\[
d \geq 3 \sqrt[3]{\frac{M_e}{0.1 \times \sigma_{-1b}}} 
\]

So the shaft diameter is 12mm after check.

5.2 The mechanism for out and in

5.2.1 Electromotor

Table 8. Parameters of motor,[11].

<table>
<thead>
<tr>
<th>Model number</th>
<th>25GA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (V)</td>
<td>DC6</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>No-load speed (r/min)</td>
<td>55</td>
</tr>
<tr>
<td>Rated Speed (r/min)</td>
<td>42</td>
</tr>
<tr>
<td>Rated Torque (Nm)</td>
<td>1.5</td>
</tr>
<tr>
<td>Rated Current (A)</td>
<td>0.2</td>
</tr>
<tr>
<td>Price (Yuan)</td>
<td>28</td>
</tr>
<tr>
<td>Weight (KG)</td>
<td>0.1</td>
</tr>
</tbody>
</table>

The output torque of the electromotor is 0.15 Nm

The output power from the electromotor is calculated as:

\[
P = \frac{T_E \times n}{9550} \times 1000
\]

where,

\[T_E\] Output torque of electromotor

So the output power is

\[
P = \frac{0.15 \times 42}{9550} \times 1000 = 0.66W
\]

While the radius of gear is 14 mm, the linear velocity of the small gear is calculated as:

\[
V_{max} = \omega r
\]
where,

\[ V_{\text{max}} \quad \text{Maximum linear velocity of gear} \]

\[ \omega \quad \text{Angular velocity} \]

\[ r \quad \text{Diameter of the small gear} \]

The international unit of linear velocity is m/s, the international unit of angular velocity is rad/s, the international unit of length is meter. Hence,

\[ V_{\text{max}} = \frac{2\pi \times V \times R}{60 \times 1000} = \frac{2\pi \times 42 \times 14}{60 \times 1000} = 6.16 \times 10^{-2} \text{ m/s} \]

The linear velocity is

The minimum output force of the electromotor is calculated as:

\[ F_{\text{min}} = \frac{P}{V_{\text{max}}} \quad (20) \]

where,

\[ F_{\text{min}} \quad \text{Minimum output force of the motor} \]

So the minimum output force is \( F_{\text{min}} = \frac{0.66}{0.0616} = 10.72\text{N} \)

Since the efficiency of the motor is 0.75, the effective output force is calculated as:

\[ F = F_{\text{min}} \eta \quad (21) \]

The effective output force is \( F = 10.72 \times 0.75 = 8\text{N} \), it means the minimum thrust is 8 N.

So, the minimum thrust force is 8 N.

5.2.2 Friction

We assumed that the max weight is 8 kg. The material of the rack is 20 steel and the semi-supported part is cast iron as marked in Figure 25. Through access to information, we know that the coefficient of friction of cast iron and 20 steel is 0.2,
Friction between the rack and platform is calculated as:

\[ f = \mu \times mg \]  

(22)

where,

- \( f \) The friction between the rack and platform
- \( \mu \) Friction factor
- \( m \) Weight

Friction for two electromotor is \( f = 16\text{N} \), so it is 8 N for one.

Since the maximum thrust force is 8 N, the electromotor 25GA type is workable.
Chapter: Modelling of components

Figure 26. Components diagram

Table 9. Component list

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Name</th>
<th>Number</th>
<th>Type</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drawer with rack</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Screw</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Shaft 1</td>
<td>1</td>
<td></td>
<td>Internordic</td>
</tr>
<tr>
<td>4</td>
<td>Bearing seat 1</td>
<td>3</td>
<td>The bearing is</td>
<td>Internordic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6801-ZZ deep groove bearing with shied</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---------------------------------------</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Bearing seat</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Bevel gear</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Bevel gear</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Sleeve</td>
<td>4</td>
<td>ZM 12 Specma Hydraulic</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Spring washer</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Stepper motor</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Spur gear 1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Plank</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Block</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Spur gear 2</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Motor</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Rack</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Drawer</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Framework</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.1 The framework of cabinet

![Figure 27. Framework of cabinet](image)

The marked place can be filled into the cylinder which is on the drawer’s racks.
Figure 28. Screw seat

This place will fasten the screw and make it work smoothly.

6.2 Drawer

Figure 29. Drawer
6.3 Bearing seat

In order to stabilize two shafts, we choose bearings and put them into the bearing seats to make the design more stable and better-looking.

*Figure 30. Bearing seat*

In order to stabilize two shafts, we choose bearings and put them into the bearing seats to make the design more stable and better-looking.
Figure 31. Big bearing seat, [14].

Type 21-125 is chosen according to the structure.
6.4 Spur gear

Figure 32. Parameter of spur gear, [14].

6.5 Plank

Figure 33. Plank

This plank supports the drawer when the design is working.
6.6 Block

Figure 34. Block

This block is connected with the plank as shown in Figure 33.
6.7 Rack

Figure 35. Parameter of rack, [14].
6.8 Screw

Figure 36. Lead screw
6.9 Sleeve

Figure 37. Parameter of sleeve, [14].

6.10 Spring washer

Figure 38. Spring washer
6.11 Stepper motor

Figure 39. Size of stepper motor, [15].
7 Chapter:  
Controlling system

Our aim is to design a mechanism making the drawer pull out, lift down and up and slide it smoothly and automatically.

![Figure 40. Control buttons](image)

Except mechanical parts, we need to design a controlling system which including the MCS-51, stepper motor drive, stepper motor, electrical motor, power supply system and so on. There are two main parts in our work; making the drawer up and down and making the drawer slide it in and out.
7.1 The circuit control for up and down

The mechanism is more likely a robot. The brain of robot is MCS-51. The stepper motor driver receives step and direction signals from MCS-51, then it converts digital pulses into mechanical shaft rotation. The magnetic sensor is used to detect the height of drawer.

*Figure 41. The schematic of system, [17].*

*Figure 42. MCS-51 core, [13].*
MCS-51 is a good MCU to learn and use, easy to getting start to build your own system.

The Intel MCS-51 is Harvard architecture, single chip microcontroller series which was developed by Intel in 1980 for use in embedded systems with multitasking real-time operating system support. It is still one of most popular microcomputers in the world.

Figure 43. Magnetic sensors, [18].

Magnetic sensors are actuated by the presence of a permanent magnet. Their operating principle is based on the use of reed contacts, whose thin plates are hermetically sealed in a glass bulb with inert gas. The presences of a magnetic field makes the thin plates flex and touch each other causing an electrical contact. The plate's surface has been treated with a special material particularly suitable for low current or high inductive circuits.

Magnetic sensors compared to traditional mechanical switches have the following advantage:

1. Non-contact with the measure object.
2. Contacts are activated by means of a magnetic field rather than mechanical parts
3. Maintenance free
4. Easy operation
5. Reduced size
Stepper motor driver we choice is DQ860MA which is brushless DC motor drivers that can be used for both positioning and velocity control applications. We use magnetic sensors as external position feedback to detect the weight of the drawer.

Table 10. The parameters of driver

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>24-80VDC</td>
</tr>
<tr>
<td>Input current</td>
<td>less than 6A</td>
</tr>
<tr>
<td>Output current</td>
<td>2.8A-7.8A</td>
</tr>
<tr>
<td>Consumption</td>
<td>Consumption 80W, Internal Insurance 10A</td>
</tr>
<tr>
<td>Temperature</td>
<td>Working temperature -10-40°, Stocking temperature -40-70°</td>
</tr>
<tr>
<td>Humidity</td>
<td>No condensation, no water droplets</td>
</tr>
<tr>
<td>Gas</td>
<td>Prohibition of combustible gases and conductive dust</td>
</tr>
<tr>
<td>Weight</td>
<td>600GS</td>
</tr>
</tbody>
</table>

Typical stepper motors consist of a rotating permanent magnet (rotor) surrounded by electromagnets (stator). When the electromagnets are supplied current in the correct polarity and sequence a torque is created that moves the rotor in steps. These steps can be sequenced together to move the rotor at various speeds corresponding to the sequence rate.
Figure 45. The switching power supply YGS-350-24, [20].

Table 11. The parameters of YGS-350-24

<table>
<thead>
<tr>
<th>OUTPUT</th>
<th>YGS-350-5</th>
<th>YGS-350-12</th>
<th>YGS-350-24</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC VOLTAGE</td>
<td>3V</td>
<td>12V</td>
<td>24V</td>
</tr>
<tr>
<td>RATED CURRENT</td>
<td>60A</td>
<td>25A</td>
<td>12.5A</td>
</tr>
<tr>
<td>RATED POWER</td>
<td>300W</td>
<td>300W</td>
<td>300W</td>
</tr>
<tr>
<td>RIPPLE&amp;NOISE</td>
<td>70mVp-p</td>
<td>100mVp-p</td>
<td>120mVp-p</td>
</tr>
<tr>
<td>VOLTAGE ADJ.RANGE</td>
<td>±2.0%</td>
<td>±1.0%</td>
<td>±1.0%</td>
</tr>
<tr>
<td>VOLTAGE TOLERANCE</td>
<td>±0.5%</td>
<td>±0.5%</td>
<td>±0.5%</td>
</tr>
<tr>
<td>LINE REGULATION</td>
<td>±1.0%</td>
<td>±0.5%</td>
<td>±0.5%</td>
</tr>
<tr>
<td>LOAD REGULATION</td>
<td>±0.5%</td>
<td>±0.5%</td>
<td>±0.5%</td>
</tr>
<tr>
<td>SETUP.RISE TIME</td>
<td>300ms/50ms/230VAC</td>
<td>800ms/50ms/115VAC at full load</td>
<td></td>
</tr>
<tr>
<td>HOLD UP TIME(TYP.)</td>
<td>90ms/230VAC</td>
<td>12ms/115VAC at full load</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INPUT</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>VOLTAGE RANGE</td>
<td>85~264VAC</td>
<td>120~370VDC</td>
<td></td>
</tr>
<tr>
<td>FREQUENCY RANGE</td>
<td>47~63Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EFFICIENCY(Typ.)</td>
<td>80%</td>
<td>85%</td>
<td>88%</td>
</tr>
<tr>
<td>AC CURRENT(Typ.)</td>
<td>6.5A/110VAC</td>
<td>3.5A/220VAC</td>
<td></td>
</tr>
<tr>
<td>INRUSH CURRENT(Typ.)</td>
<td>COLD START</td>
<td>25A/115VAC</td>
<td>50A/230VAC</td>
</tr>
<tr>
<td>LEAKAGE CURRENT</td>
<td>&lt;0.75mA/240VAC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The switching power supply is YGS-350-24, it is an electronic power supply that incorporates a switching regulator to convert electrical power efficiently. Like other power supplies, an SMPS transfers power from a source. We use YGS-350-24 as the switching power supply. The output voltage is 24V and the rated current is 12.5A.

7.2 The Circuit control for out and in

In the controlling system for sliding the drawer out and in, the MCs-51 as shown in Figure 42 controls two electrical motors (25GA). The motor driver chip we choice is LG9110. It can control the electrical motors positive inversion. When motors rotate forward, the pinions mesh the racks and slider the drawer out.
We use magnetic sensor as shown in Figure 43 to detect the position of the drawer. While the user touches the forward button, the drawer will be moved out from the original position. After the drawer has been slid out, the sensor will send an electrical signal to the MCS-51, and then it will stop the motor.

While the user touches the back button, the motors rotate backward. When the drawer goes back to the original position, the sensor will send another electrical signal to the MCS-51 stopping the motor.

The operating voltage of electrical motor is 6V. We use the battery to supply the motor. The battery we choose is Panasonic BR-AGCF2W. It is a replacement 6 Volts 1800mah Lithium battery.
### Table 12. The price list of controlling system

<table>
<thead>
<tr>
<th>Controlling System</th>
<th>Unit Price [SEK]</th>
<th>Amount</th>
<th>Total Price [SEK]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCS-51 core</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Magnetic sensors</td>
<td>8</td>
<td>6</td>
<td>48</td>
</tr>
<tr>
<td>DQ860MA driver</td>
<td>320</td>
<td>1</td>
<td>320</td>
</tr>
<tr>
<td>YGS-350-24</td>
<td>38</td>
<td>1</td>
<td>38</td>
</tr>
<tr>
<td>Battery BR-AGCF2W</td>
<td>50</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td><strong>461</strong></td>
</tr>
</tbody>
</table>
8 Chapter: Application

The following steps are shown how it works.

First, press the button and the plank will start to move from the top as shown in Figure 48.

![Figure 48. Plank on top](image)

Secondly, the plank will stop by touching the sensor we introduced before controlled by gear box.

![Figure 49. Plank stopped on sensor place](image)
Thirdly, the gear will mesh the rack accurately in terms of the equipment touching the staff on the rack as shown in.

![Figure 50. The mesh between rack and gear](image)

Fourthly, the drawer comes out through the racks controlled by the small motor as shown in Figure 51.

![Figure 51. Drawer comes out](image)

Fifthly, the drawer goes down automatically by gear box as shown in Figure 52.
Finally, take out or put inside the things and press the button to make drawer go to the original position and go inside and the plank will come to the top.

The gear box is a simple mechanism. The stepper motor controls the gear and the gear meshes each other to make the screw keep working.
Chapter: Verification

Figure 53. The rack stress analysis

In order to get maximum stress and the safety factor of the components of the design, we use ABAQUS which is an analysis software to calculate the parameters.

Figure 54. Rack mashes gear

This is our rack which mashes gear to make the drawer go out and inside. We want to make sure that if it is safe when two racks can support eight kilograms that means one rack can support four kilograms in this case. The material we select is No.20 steel.
Figure 55. Load setting

We set up the initial maximum load for one drawer as eight kilograms, so we choose this data as the stress to analyze the device.
Figure 56. Constraints

The cuboids which is noticed by some small orange points is fixed. When the rack is stuck in the plank, it cannot move along y and z.
We divide the device into six parts to establish the meshing function. The software can generate view automatically. The pictures following show the detail data. 320 allowable stress.

The pictures following show the detail data that the max stress is 5.073 Mpa. According to the machinery's handbook [22], the allowable stress of 20 steel is 137 Mpa. So, The structure is definitely safe and reliable.
10 Chapter: Conclusion

10.1 Conclusion

- Our device occupies 700 mm×400 mm×1130 mm.
- The main material of framework is wood, thickness is 15 mm. The material of other components are main steel, details in the parts drawings.
- Three drawers are installed on the cabinet. Two of them are movable. Each drawer can be filled with 7 kg.
- THK DCMB20 + 530LT is controlled by motor 85BYGH45C-012 to implement the up and down movement; while rack and semi-supported structure are controlled by electromotor 25GA to implement the out and in movement.
- MCS-51 is used to send signals; the magnetic sensor is used to detect the position of the drawer; DQ860MAdriver is chosen as motor driver; YGS-350-24 is chosen to be the switching power supply.
- Panasonic BR-AGCF2W is chosen as the battery for the electromotor.
- The device costs SEK 1,800 for all components.

10.2 Future work

In future a prototype can be built to see the effectiveness of this design. A market survey will provide cost estimation to build this project. The linkage mechanism for automated cabinet as mentioned in this project can be an interesting study to do in future.
Reference


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