Automatic Control of Shower Equipment for Elderly People or People with Physical Disabilities

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Karlskrona, Sweden/ 2012

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Abstract:
In this thesis an electronically controlled moveable chair is designed to be connected to the door of a shower. A bathroom model was created using Autodesk Inventor, and materials were researched and selected for modeling before doing a static simulation. A dynamic simulation was then carried out to simulate the vertical motion of the chair; the driving torque was generated at the same time. Based on the driving torque, a direct current motor which connects with a system controlling the vertical direction movement of the chair was designed and built.

Keywords
Autodesk Inventor, Electronic Control, Materials Selection, Static Simulation, Dynamic Simulation, Direct Current Motor, Control Box.
Acknowledgements

This work was carried out at the Department of Mechanical Engineering, Blekinge Institute of Technology, Karlskrona, Sweden.

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We also would like to thank our classmates who helped us use CAD Auto inventor. We are grateful for their constant support and help.

Karlskrona, March 2012

QiLiang Zhao
Yaqi Zhou
Fan Zhang
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1. NOTATIONS

A     The cross-section area
C     Torsional stiffness
dm    The outer thread diameter of cross section of rolled ball screw
dr    The inner thread diameter of cross section of rolled ball screw
F     Load capacity
Fs    Safety factor
G     Shear module
g    Gravitational acceleration
I     Area moment of inertia
L     Length of rolled ball screw
m     Mass
n     Outer shaft speed
P     Pressure distribution
Prated  Rated power
Preal  Real power
Ph    The length of lead
R     Diameter
r    Radius from spring Centre to location Centre
T     Torque
t    Thickness of material
V     Voltage
σ     Normal stress
σv    Von Mises Stress
σy    Yield Stress
β     Lead angle
ηf    Forward efficiency
ηs    Service efficiency
θ     The allowable unit length torsion angle
ρ     Density
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Alternative current</td>
</tr>
<tr>
<td>DC</td>
<td>Direct current</td>
</tr>
<tr>
<td>SMC</td>
<td>Sheet molding compound</td>
</tr>
<tr>
<td>PCB</td>
<td>Printed Circuit Board</td>
</tr>
<tr>
<td>PLC</td>
<td>Programmable logic controller</td>
</tr>
<tr>
<td>PMMA</td>
<td>Poly (methyl methacrylate)</td>
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</tbody>
</table>
2. INTRODUCTION

2.1 Background

It is known that aging is a phenomenon that affects everyone, not only the elder population. Of the more than 220 countries and territories worldwide, over 60 have entered the realm of the aging society. By the year 2025, the worldwide population of people over the age of 60 is expected to reach 1.12 billion. By 2050, the number will increase to 2 billion, accounting for about 21% of the total world population [1]. That means every ninth person in the world is aged 60 and above currently, and their numbers will increase to one in five by 2050. This number will be much larger than the number of children under the age of 14. By 2150, one out of three persons will be 60 years or older [1].

Figure 2.1.1 shows the world population in developed and developing countries in 1960, 2000 and projected population for 2040. According to the figure, the aging population increases dramatically over these 80 years and, as noted above, it is believed that aging population will keep rising in the future.

The growing population of aging people contributes to a growing consumer market. The health care market especially becomes much more relevant to people over the age of 60. A great number of health care products have been created to improve life qualities of elderly or people with physical disabilities. In the United States, several components contribute to consumption expenditures. Data from 2003 indicate that, until about age 65, rising consumption is fueled by increasing private expenditure in both private health care and private durable goods [2]. It becomes the basis of the idea of this thesis.
In Sweden, the number of people over the age of 65 is equal to 17% of the country's total population. The social endowment insurance system was set up in Sweden in early 1950s. As the economy and society progress, the social endowment insurance system has been greatly improved. However, the needs of elderly people in some aspects are still left unmet. More
innovative facilities and apparatuses tailored for the elderly and people with disabilities are needed in order to improve the quality of their lives. And also, the transformation from scientific and technological achievements into actual productivity needs to be further enhanced [4].

2.2 Aim and Scope

This thesis builds on a 2011 bachelor thesis in the field of health care titled "Easy Access Shower for Elderly and People with Disabilities"[5], which introduced a moveable chair installed on the door of shower. However, that thesis was only based on theoretical knowledge. The aim of this thesis is to design and produce a convenient and safe shower environment for elderly people or people with physical disabilities. Based on the learning from the previous thesis, this thesis aims to address: easy access to the shower room, electronically controlled movement of the chair, uncomplicated operation of the electronic control system, and basic thoughts about waterproofing of the electric control system.
3. MODELING AND DESIGN

Using the design software described below, a model of a standard bathroom was created in order to get a deeper understanding of the construction. Then an improved shower model was envisioned and designed.

3.1 Software instructions

The software programs used in this thesis are Autodesk Inventor 2012 professional and DXP PROTEL 2004. Autodesk Inventor 2012 professional is used for modeling the bathroom, to create a static and dynamic simulation. DXP PROTEL 2004 is mainly used for designing the principle circuit sheet of the control box in this case.

3.2 Standard Bathroom Model

![Top view of a standard bathroom]

*Figure 3.1.1 Top view of a standard bathroom*
Figure 3.1.1 is a model of a standard manual bathroom created using the software Autodesk-Inventor. This model was created in order to get a deeper understanding of the construction. The model is based on a bathroom in the J building of the Blekinge Tekniska Högskola.

### 3.3 Optimized Design

Improvements to this bathroom design are to install a vertically moving chair on the door. To implement this design appropriate mechanical equipment and materials must be selected. To achieve vertical movement of the chair, slide ways and rolled ball screws must be installed to connect the door with the chair. A control box will be designed to drive the motor, and then, a motor must be designed to deliver the driving force to the moving chair to achieve automatic control. Mechanical components, material selection, simulation and analysis of chair movement, and design and construction of the electronic control box will be introduced and described in detail in the following sections.

### 3.4 Main Mechanical Equipment

The main mechanical components needed for the vertically moving chair are: a door, hinges, slide ways, rolled ball screw, seat, safety arm rest, and coupling. Each of these components is described in more detail below. Material selection will be addressed in the following section.
3.4.1 Door

The door is the key component in our design and is the main load-bearing part.

3.4.2 Hinge

The hinge is the mechanical device used for connecting two solids, and allows for rotating. The most common hinge is installed on doors and windows. Hinges are basically divided into two types: direct insertion or self-dumping according to different installation combinations. The most commonly used angles for the door opening are 95-110 degrees. Materials used for hinges are mainly stainless steel and iron.

Hinge size can be divided into the following in accordance with the specifications:
2"(50mm), 2.5" (65mm), 3 "(75mm), 4" (100mm);
3.4.3 Slide Way

A slide way refers to grooves or ridges made of metal or other materials, which can bear up, fix and guide a mobile device or apparatus. It is a part of device for reducing the friction. The longitudinal groove or ridge on the rail surface is used for guiding and fixing machine parts, special equipment, instruments and the like. The rail is also known as sliding rail, linear guiding rail and linear guide way for linear reciprocating motion occasions. It has a load rating which is higher than the linear bearings and can assume certain torque at the same time. It can also achieve high precision linear motion in the case of high load.
3.4.4 Rolled Ball Screw

Figure 3.2.2.4 Rolled ball screw

A rolled ball screw is used for converting rotary motion into linear motion, or converting linear motion into rotary motion. A ball screw is composed of a screw, a nut, a steel ball, a pre-tablet, a reversing device, and a dust preventer. Since the bearing is changed from scrolling action into sliding action the frictional resistance is relatively small. When the ball screw is used as the active body, the nut can be converted into linear action according to lead of corresponding specification along with the screw rotational angle, passive work pieces can be connected through the nut holder and nut in order to achieve corresponding linear movement.
3.4.5 Seat

The seat is designed for elderly and physically disabled people, thus the key points are the height of the chair seat and backrest issues. The sitting height of the average person is about 60 centimeters, but wheelchair seat height is generally 41cm so the lowest height of our mobile seat is set to be 41cm away from the ground. The chair armrest is set to be 20 to 30 cm to allow the user to reach for articles to the left and right. The backrest is generally titled a 15 degree angle, which is in line with ergonomics.

3.4.6 Safety Armrest

Increasingly degraded physiological function leads to the decline in muscle strength and balance deterioration, and the possibility of a fall in the bath among the elderly is rising. Therefore, the role of the safety armrest is very important. The safety armrest is to maintain the balance of the body or to support the body, and it can efficiently transfer the elderly from the wheelchair to the revolving door. At the same time, it can effectively prevent the elderly from falling or slipping on the wet floor.

For our design, we selected existing bathroom armrests for direct application. The armrest could be made of the following materials: Copper, stainless steel or aluminum. It can be in the following shapes: U-type armrest, rotating armrest and Chlorophytum type armrest.
3.4.7 Coupling

The couplings are used for joining two shafts in different institutions (the drive shaft and the driven shaft), thereby they can rotate together in order to transmit torque mechanical parts. The coupling is composed of two parts which are respectively connected with the drive shaft and the driven shaft. The coupling also has the function of cushioning, damping and improving the dynamic performance of shafting; general power machines are mostly connected with the working machines by means of coupling.
4. MATERIALS

4.1 Importance of Material Selection

The optimized bathroom renovation design described here is based on convenience, safety, easy cleaning and beautiful appearance. Since the bathroom is very humid, the design is mainly based on waterproof materials.

4.2 Basic Material Characteristics of Bathroom

In a design aimed at the elderly and physically disabled persons, the designer should pay special attention to the following points during material selection:

1. Shape: highly reflective material should not be adopted to reduce glare stimulus on elderly eyes.
3. Price: the cost should be low to make our products more competitive.
4. Product life cycle: physical properties.
5. Corrosion resistance: chemical properties.
6. Weight per unit area: m (the PV object with unit volume).
4.3 Material Characteristics of Door

![Door Image](image)

*Figure 4.3.1 Door*

In the optimized design, in order to choose the door and seat material, the design team did a market investigation and found that there are four kinds of material widely used in the design of the load-bearing door. The following steps were taken to select the material: 1). Knowledge of the material characteristic, 2). compare the data in the real situation, 3). choose the most suitable material.
4.3.1 Wood (Xylosma oak)

Trees are divided into two categories: conifers and broad-leaved trees. Conifers are straight; the wood quality is relatively soft with easy processing and small deformations. Broadleaf has a denser, harder wood quality; it is more difficult to process, easily split, has a beautiful texture and is suitable for indoor decoration.

The Xylosma oak quality is light; the Density of the material is 0.63 to 0.72 g/cm³ [6]. Strengths in each direction are inconsistent. It has higher density, the compression strength parallel to grain is 155.4 MPa [7, 8], but the compression strength perpendicular to grain the maximum value is 3.7 MPa, so this material can be easily deformed. It is perishable and flammable with uneven texture. It is easily processed and some species have beautiful texture; the price of the Xylosma oak is 4025-4661 SEK/m³ [9]. The volume of the door is 0.0738m³ (Length 2050mm × Height 900mm × Width 40mm). So the door should cost between 298 to 343 SEK.
4.3.2 Stainless Steel

Stainless steel is one of the materials with the highest density among the metal materials for construction. It has good formability and good weldability, and can be used as the ultra-high-strength materials. Surface appearance is good, the use possibility is diversified by its excellent corrosion resistance. It has long-term durability, high corrosion resistance and high strength compared with ordinary steel, thus the possibility of thin sheet use possibility great. With high-temperature oxidation and high strength, it can resist fire. Normal temperature processing makes it easily maintained and simply cleaned.

Material quality is moderate; the density is 7650 kg/m³ [10]. It has higher strength and the allowable stress is 448 MPa. [7, 8] This material is easy to process mechanically; it has beautiful surface and high corrosion resistance; the price is relatively higher compared with natural materials. The stainless steel price is 9262-9924 SEK/Ton [11]. If using the stainless steel to build the door, the mass is 56.5kg. So the door should be cost between 523 to 561 SEK.
4.3.3 Iron

Figure 4.3.3.1 Iron

Iron is chemically reactive, and it is prone to rusting and electrochemical corrosion in moist air. The corrosion is faster in acidic gas or halogen vapor atmosphere. It must be given a preservative treatment if used in bathroom.

Material quality is high; the density is 7860 kg/m3 [12, 13] and the allowable stress is less then stainless steel. The value is 160 to 220 MPa [7, 8]. The iron price is 3308-5292 SEK/ton[14]. So the imputed price should be 412 to 487 SEK.
PMMA has smooth surface and the quality is lighter; the density is 1220 kg/m$^3$. The light transmittance is high; it has certain heat resistance, cold resistance, weather resistance, corrosion resistance, and good insulation properties, and can be easily formed in general cases. The allowable stress is 70 MPa. [7, 8] The texture is more brittle with easy aging and high surface hardness; it can be easily dissolved in low ketones, esters and benzene - soluble organic solvent. The price of the Organic Glass PMMA is 12.4 SEK/kg [15] for thickness 40mm. Therefore the cost should be 1116 SEK.
### 4.3.5 Door Material Selection

In mechanical design or engineering structure design, there is a maximum stress value that parts or components can bear. In order to judge the maximum or minimum working stress of parts or components loaded, a standard measurement of allowable stress shall be predefined. When the working stress of parts or components is no more than the allowable stress, the parts or components are safe in operation, otherwise it is unsafe. As a basic data in mechanical design and engineering structure design, allowable stress equals the safety factor divided into the material’s failure stress (yield limit or strength limit in static strength design or fatigue limit in fatigue strength design) that is modified appropriately after considering all influencing factors.

Plastic material sets the yield limit as a basic standard that is divided by the safety factor and yields the allowable stress. Known as,

\[
[\sigma] = \frac{\sigma_s}{n} \quad (n=1.5\sim2.5). \quad (4.1)
\]

Brittle material sets the strength limit as a basic standard that is divided by the safety factor and yields the allowable stress [16].

\[
[\sigma] = \frac{\sigma_b}{n} \quad (n=2\sim5). \quad (4.2)
\]

<table>
<thead>
<tr>
<th>Material</th>
<th>Allowable stress [\sigma] (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood (Xylosma oak)</td>
<td>3.7-154</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>448</td>
</tr>
<tr>
<td>Iron</td>
<td>160~220</td>
</tr>
<tr>
<td>Organic Glass PMMA</td>
<td>70</td>
</tr>
</tbody>
</table>

*Table 4.3.5.1 Allowable stress*

From the table 4.3.5.1, the stainless steel has the maximum allowable stress 448 MPa, and the Organic Glass PMMA just has 70 MPa. In this section,
the door is the key component in the optimized design and is the main load-bearing device. The larger allowable stress means the door can bear larger load. At the same time, time and price should be considered as well. Except for Iron plate, the other three kinds of material have very high physical and chemical stability properties, therefore only the price of the materials needs to be considered. In Table 4.3.5.2, the material price of the Organic Glass PMMA is too expensive; the material price is two times more than other three materials.

Based on the allowable stress and price comparisons, stainless steel will be the top priority material for the door.

<table>
<thead>
<tr>
<th>Material</th>
<th>Imputed price (SEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood (Xylosma oak)</td>
<td>298-341</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>523-561</td>
</tr>
<tr>
<td>Iron</td>
<td>412-487</td>
</tr>
<tr>
<td>Organic Glass PMMA</td>
<td>1116</td>
</tr>
</tbody>
</table>

### Table 4.3.5.2 Price comparison

#### 4.4 Material Characteristics of Seat

#### 4.4.1 General Types and Materials of Seats

There are many bathroom seats with different functions on the market. Each will be introduced below.

(1) Movable seat types
The seat can be placed at random, the seat height is fixed, it requires manpower to move, and takes up some space. The materials used consist of aluminum, plastic and wood, single or mixed. (See figure
4.4.1.1, figure 4.4.1.2 and figure 4.4.1.3)

Figure 4.4.1.1. Movable seat type [17] (1)

Figure 4.4.1.2. Movable seat type [18] (2)
(2) Fixed seat types
This type of seat is fixed to the shower wall; it has a fixed height, occupies a large space, cannot be moved, and most of the frames are high-strength composite materials. (See figure 5.4.1.4 & 5.4.1.5)

![Figure 4.4.1.4 Fixed seat type [19] (1)](image1)

![Figure 4.4.1.5 Fixed seat type [20] (2)](image2)

(3) Fixed folding seat type
This type of seat is fixed to the shower wall at a fixed height; this type can save a little space and cannot be moved; the frame is made of high-strength composite materials. (See figure 5.4.1.6)
4.4.2 Seat Material Selection

The seat in the optimized design has two parts: the covering, and the frame.

4.4.2.1 Seat Covering Material Selection: Sheet Molding Compound

Figure 4.4.1.6. Fixed folding seat type [21]

Figure 4.4.2.1.1 Sheet molding compound seat [16]
SMC composite has the characteristics of firmness, abrasion resistance, thermal insulation, good skin feel, insulation, anti-aging, anti-high temperature, non-slip watertight performance, non-absorbent performance, easy cleaning, long service life, non-porous surface after a service life of over 20 years, smoothness, density, no sharp corners, easy to clean, and significant savings in cleaning costs.[22]

In the mechanical design, SMC molded articles have high mechanical properties, thermal stability and chemical corrosion resistance. The product is integrally molded, the product design has no seam; the size and shape of the product are unlimited; it can be produced fast and is lightweight, the density just has 1700kg/m³. The cost of the sheet molding compound is just 61-122 SEK/unit [23].

4.4.2.2 Frame Material Selection: Aluminum Alloy

![Figure 4.4.2.2.1 Aluminum alloy](image)

*Figure 4.4.2.2.1 Aluminum alloy*
Aluminum alloy includes the following performance properties: low density, high strength approximate to or better than high-quality steel, good plasticity to be processed into various sections, excellent electrical conductivity, thermal conductivity and tarnish resistance, light weight. If steel plate material is replaced by aluminum alloy in the welding, the structure weight will be reduced by over 50% with good deformability. It is very good material for the frame. [24]

6000 series aluminum alloy [25] contains two elements of magnesium and silicon and embodies the advantages of the 4000 series and 5000 series. 6061 series, a kind of cold processing and aluminum forging product, is appropriate for exposure to high demanding corrosion and oxidation resistance. It has good usability, easy coating and fine deformability.

The seats on the market are mostly made of aluminum alloy. The maximum allowable stress is 370MPa, but the result obtained by static analysis is lower than its maximum allowable stress. So the frame of the seat will be made of aluminum alloy.
5. SIMULATIONS AND ANALYSIS

5.1 Stress Analysis under Static Conditions

The software Autodesk Inventor Professional 2012 was used for the static simulation of two models (Model 1 and Model 2) which were created to calculate where the maximum Von Mises Stress appears to lead to a plastic failure in the selected materials.

5.1.1 Model 1 Introduction

Model 1 contains two slide ways, one rolled ball screw, a chair, and 16 screws (six each for two slide ways and four for the rolled ball screws), shown in the figure below (see figure 5.1.1.1).
In this figure one can also see that only parts of slide ways and rolled ball screw are shown, because those parts which are connected with screws are the significant parts which need to be considered.

The slide ways and rolled ball screw are made of stainless steel, 440C, the chair is made of aluminum-6061-AHC, and all of the 16 screws are made of stainless steel, 440C.

A load, constraints and boundary conditions will be added to this model to get the following static simulation results in following. A maximum Von Mises Stress and its location will be calculated by Autodesk Inventor automatically. By knowing the maximum Von Mises Stress and its location, and the safety factor, one can calculate for the material where the maximum Von Mises Stress appears to lead to a plastic failure.

5.1.1.1 Load Added on Model 1

A concentrated force is added on the surface of the chair back shown in figure 5.1.1.1.1.
A person weighting 80 kg is assumed to sit on the chair and a motor weighting 5 kg supports the motion of the rolled ball screw is under the chair. Assuming that the gravity coefficient equals 10 N/kg, one can calculate that the concentrated force equals to 850 N.

It is known that a homogenously distributed load pressure is more accurate in this case; however, in order to get a larger Von Mises Stress, a concentrated force is used here because it is important to consider the most dangerous case in mechanical engineering. If the material can bear the more dangerous case, it can bear the safer cases easily.

### 5.1.1.2 Boundary Conditions of Model 1

Model 1 is attached at a surface (which will be connected to the door), shown in figure 5.1.1.2.1.

*Figure 5.1.1.2.1 Boundary conditions of Model 1*
5.1.1.3 Results of Model 1

Results were obtained by inputting the material, load, constraints, and boundary conditions, by creating mesh in Autodesk Inventor.

The maximum Von Mises Stress equals 10.27 MPa shown in figure 5.1.1.3.1, and the maximum displacement is 0.001697mm shown in figure 5.1.1.3.2

Figure 5.1.1.3.1 Maximum Von Mises Stress of Model 1

Figure 5.1.1.3.2 Maximum displacement of Model 1
5.1.1.4 Calculations

The Von Mises Stress is an equivalent stress calculated by the criterion of strain energy density corresponding to distortion. According to this theory, its value should be smaller than the yield stress of the material divided by the safety factor, which is

$$\sigma_v < \frac{\sigma_y}{F_s} \quad (5.1)$$

Where $\sigma_v$ is Von Mises Stress, $\sigma_y$ is yield stress, and $F_s$ is the safety factor.

By knowing the location where the maximum Von Mises Stress appears and the safety factor, one can easily check the material and then check the value of the yield stress of this material. One can then calculate if a plastic failure appears in the material, here is the calculation:

$$\sigma_v = 10.27 \, Mpa$$
$$\sigma_y = 448 \, Mpa$$
$$F_s = 3$$

From equation 5.1, one can calculate:

$$\frac{\sigma_y}{F_s} = \frac{448}{3} \approx 149.3 \, Mpa > \sigma_v$$

No plastic failure occurs. This means that Model 1 is strong enough to support an 850 N force.
5.1.1.5  Result by Using Pressure Distribution

It is known that pressure distribution is more accurate in this case, so we did the static simulation again by using pressure distribution instead of concentrated force.

The area of the top of the chair back is measured to be $6500 \text{mm}^2$, and the force equals to 850 N, thus the pressure distribution is set to be 0.13 MPa.

The constraints, the boundary conditions, and mesh are all set to be same as the simulation process by using concentrated force to get an objective result for comparison. Here are the results:
The maximum Von Mises Stress equals 10.25 MPa shown in figure 5.1.1.5.1, and the maximum displacement equals to 0.001694 mm shown in figure 5.1.1.5.2.

![Figure 5.1.1.5.1 Maximum Von Mises Stress of Model 1(By using pressure distribution)](image)

*Figure 5.1.1.5.1 Maximum Von Mises Stress of Model 1(By using pressure distribution)*
Figure 5.1.1.5.2 Maximum displacement of Model 1 (By using pressure distribution)

5.1.1.6 Comparison

Table 5.1.1.5.1 includes the results of the Von Mises Stresses and displacements determined by using both concentrated force and pressure distribution.

<table>
<thead>
<tr>
<th></th>
<th>Concentrated force</th>
<th>Pressure distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Von Mises Stress (MPa)</td>
<td>10.27</td>
<td>10.25</td>
</tr>
<tr>
<td>Displacement (mm)</td>
<td>0.001697</td>
<td>0.001694</td>
</tr>
</tbody>
</table>

5.1.1.7 Discussions on Stress Analysis

In Model 1, the maximum Von Mises Stress appears at one of the screws just as expected; after the calculation, we know that no plastic failure occurs for this screw. And the maximum displacement appears at the chair back, equals to 0.001697 mm, which is really small.
In this model, only the seat back was considered in the static simulation. However, in the real case, the concentrated force should be added to the seat surface; the maximum displacement should appear at the edge of the seat and it should be larger. We also simulated this case (the chair with seat), and the result matches the assumptions described in 5.1.1.1.

To verify the assumption that the Von Mises Stress and the displacement calculated by using concentrated force are larger than those calculated using pressure distribution, we did the static simulation process again but changed the concentrated force to pressure distribution, and kept other steps the same. We found out that the Von Mises Stress and the displacement got by using pressure distribution are slightly smaller, which verified the assumption.

5.1.2 Model 2 Introduction

Model 2 contains a small part of the wall, some screws, two door joints, one door, two slide ways, one rolled ball screw, and a chair, shown in Figure 5.1.2.1. The materials and the quantities of each part of Model 2 will be introduced below.
5.1.2.1 Materials and Quantities of Parts of Model 2

The materials and the quantities of each part of Model 2 are introduced in the Table 5.1.2.1.1. Three materials of the door are chosen and kept the other components (wall, screw, door joints chair, rolled ball screw and slide ways) materials the same to get a comparison from which to choose the best door material.

Table 5.1.2.1.1 Materials and quantities of each parts of Model 2

<table>
<thead>
<tr>
<th>Materials</th>
<th>Quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall</td>
<td>Portland Cement Concrete 1</td>
</tr>
<tr>
<td>Screw</td>
<td>Stainless Steel, 440C 26</td>
</tr>
<tr>
<td>Door</td>
<td>Stainless Steel, 440C 1</td>
</tr>
<tr>
<td>Door joints</td>
<td>Steel, High Strength Low Alloy 2</td>
</tr>
<tr>
<td>Chair</td>
<td>Aluminum-6061-AHC 1</td>
</tr>
<tr>
<td>Rolled ball screw</td>
<td>Stainless Steel, 440C 1</td>
</tr>
<tr>
<td>Slide ways</td>
<td>Stainless Steel, 440C 2</td>
</tr>
</tbody>
</table>
5.1.2.2 Load Added on Model 2

A concentrated force of 850 N is added on the surface of the chair shown in Figure 5.1.2.2.1.

![Load and gravity direction added to Model 2](image)

*Figure 5.1.2.2.1 Load and gravity direction added to Model 2*

5.1.2.3 Boundary Conditions of Model 2

Model 2 is attached to 2 surfaces of wall shown in Figure 5.1.2.3.1.
5.1.2.4 Results of Model 2

By inputting the material, load, gravity direction, boundary conditions and by creating mesh in Autodesk Inventor, results will be easily obtained.

The maximum Von Mises Stress is 28.11 MPa shown in Figure 5.1.2.4.1 and the maximum displacement is 0.05807 mm shown in Figure 5.1.2.4.2.
5.1.2.5 Calculations

By knowing the maximum Von Mises Stress and its location, and the safety factor, we can calculate if the material appears to fail, here is the calculation:

\[ \sigma_v = 28.11 \text{MPa} \]
\[ \sigma_y = 448 \text{MPa} \]
\[ F_s = 3 \]

From equation 5.1, one can get:

\[ \frac{\sigma_y}{F_s} = \frac{448}{3} \approx 149.3 \text{MPa} > \sigma_v \]

Thus, no plastic failure occurs.
5.2 Calculations of Torsional Stiffness of the Rolled Ball Screw

The reason for calculating torsional stiffness is to provide the parameter during dynamic simulations. Since rotation is the main operating movement, it is necessary to determine torsional stiffness. The main calculation we focused on in this section is the torque $T$ that the rolled ball screw could apply.

Assume that the rolled ball screw with a non-circular cross section has a torque $T$. The length of the rolled ball screw is $L=0.35$ m, the outer thread diameter $d_{m}=14.5$ mm, inner diameter $d_{r}=11$ mm, and diameter of the rolled ball screw $d=14$ mm. The material of the rolled ball screw is stainless steel 440C which has a shear modulus $G=8.07 \times 10^{10}$ N/m$^2$. The maximum shear stress and torsional stiffness will be calculated using the finite element method described later in this chapter.

![Figure 5.2.1 Cross section of the rolled ball screw](image)

5.2.1 Methods

The Saint-Venant torsion theory [26] was applied where torsion of non-circular rolled ball screw can be obtained. The differential equations of equilibrium with no body force are shown as below.
\[
\frac{\partial \sigma_{xz}}{\partial z} = 0 \\
\frac{\partial \sigma_{yz}}{\partial z} = 0 \\
\frac{\partial \sigma_{yz}}{\partial x} + \frac{\partial \sigma_{xz}}{\partial y} = 0 \\
\frac{\partial}{\partial x} \left( \frac{1}{G} \frac{\partial \phi}{\partial x} \right) + \frac{\partial}{\partial y} \left( \frac{1}{G} \frac{\partial \phi}{\partial y} \right) + 2\theta = 0
\]

(5.2)

Where \( \sigma_{xz} = \frac{\partial \phi}{\partial y} \); \( \sigma_{yz} = -\frac{\partial \phi}{\partial x} \); \( \theta = \frac{d\phi}{dz} = C \)

The weak form (Green-Gauss theorem) [27]

\[
\left( \int_{A} B^T D B dA \right) a = \int_{L_a} N^T \frac{1}{G} \frac{d\phi}{dn} dL + \int_{L_a} N^T \frac{1}{G} \frac{d\phi}{dn} dL + 2 \int_{A} N^T \theta dA
\]

(5.3)

Figure 5.2.1.1 Mesh of the cross section of the rolled ball screw
According to Figure 5.2.2.1, the area of each triangle could be gained conveniently for which B matrix calculations. Before that, a shape function was introduced.

\[
N_i^e = \frac{1}{2A^e} [x_j y_k - x_k y_j + (y_j - y_k)x + (x_k - x_j)y] \quad (5.4)
\]

\[
N_j^e = \frac{1}{2A^e} [x_k y_i - x_i y_k + (y_k - y_i)x + (x_i - x_k)y] \quad (5.5)
\]

\[
N_k^e = \frac{1}{2A^e} [x_i y_j - x_j y_i + (y_i - y_j)x + (x_j - x_i)y] \quad (5.6)
\]

B matrix

\[
B^e = \frac{1}{2A}[ \begin{bmatrix} y_j - y_k & y_k - y_i & y_i - y_j \\ x_k - x_j & x_i - x_k & x_j - x_i \end{bmatrix} ] \quad (5.7)
\]

For triangle meshing, load factor matrix:

\[
f_i^e = 2 \int_A N^e T \theta dA = \frac{2 \theta}{3} A_e \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}
\]

5.2.2 Solutions

Global stiffness matrix [K] was gained by MATLAB (Table 6.2.2.1)
Table 5.2.2.1 Global stiffness matrix \([K]\)

Global load factor \(\{fl\}\):

\[
\{f_l\} = \begin{bmatrix}
6.7738e-10 \\
1.3548e-9 \\
1.3548e-9 \\
1.3548e-9 \\
1.3548e-9 \\
1.3548e-9 \\
1.3548e-9 \\
6.7738e-10 \\
6.7738e-10 \\
1.3548e-9 \\
1.3548e-9 \\
1.3548e-9 \\
1.3548e-9 \\
1.3548e-9 \\
6.7738e-10 \\
4.0643e-9 \\
4.0643e-9
\end{bmatrix}
\]

According to Eq.6.1, \(\{a\}\) can be calculated.

Boundary conditions are:

\[
\phi_1 = \phi_2 = \phi_3 = \phi_4 = \phi_5 = \phi_6 = \phi_7 = \phi_8 = \phi_9 = \phi_{10} = \phi_{11} = \phi_{12} = \phi_{13} = \phi_{14} = 0
\]

Others are:
$\phi_{15} = 40.2068, \quad \phi_{16} = 86.1395$

$$\{a\} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 87.4536 \\ 216.1400 \end{bmatrix}$$

The torque for the ball screw based on the results.

$$D = \begin{bmatrix} \frac{1}{G} & 0 \\ 0 & \frac{1}{G} \end{bmatrix} = \frac{1}{G} \cdot I \quad (5.8)$$

$$B = \begin{bmatrix} \frac{\partial N_1}{\partial x} & \frac{\partial N_2}{\partial x} & \cdots & \frac{\partial N_n}{\partial x} \\ \frac{\partial N_1}{\partial y} & \frac{\partial N_2}{\partial y} & \cdots & \frac{\partial N_n}{\partial y} \end{bmatrix} \quad (5.9)$$

$$a = \begin{bmatrix} \phi_1 \\ \phi_2 \\ \vdots \\ \phi_n \end{bmatrix} \quad (5.10)$$

The torsional stiffness matrix $[K]$

$$K^e a^e = f^e, \quad f^e = f_b^e + f_l^e$$
\[ K^e = \int_{A_e} B^e T D B^e dA \] (5.11)

where \( D = \frac{1}{G} \ast I \)

\[ f_b^e = \int_{L_b} N^{eT} \frac{1}{G} \frac{d\phi}{dn} dL + \int_{L_o} N^{eT} \frac{1}{G} \frac{d\phi}{dn} dL \] (5.12)

\[ f_l^e = 2\theta \int_{A} N^{eT} dA \] (5.13)

Global matrix would be written as:

\[ [K]\{a\} = \{f_b\} + \{f_l\} \] (5.14)

### 5.2.3 Results

To find these results as simply as possible the meshing work has been done in an arbitrary separation by hand for the cross section of the rolled ball screw, moreover, the cross section was divided into 12 elements in Figure 5.2.1.1.

\[ T = 2 \sum_{\alpha=1}^{n_2} a^e \left( \int_{A_e} N^e dA \right) = 0.0123 \, Nm \]

The torsional stiffness \( C \):

\[ C = \frac{T}{\theta} = \frac{0.0094}{10^{-4}} = 123 \, Nm^2 \]

The torsional stiffness was calculated for the dynamic simulation described in the following analysis section.
5.3 Dynamic Analysis

In our optimized design, we treat the electrical machine as the source of force; the rotary motion of the ball screw is converted into the rectilinear motion of the slider, which makes the seat move up and down. Through dynamic analysis, at first, we need to find out the driving force required by the motion of the seat. Then, the torque that the screw needs to rotate shall be calculated. Finally, we shall determine the model of the electrical machine. We can more intuitively see the overall process of system working through dynamic analysis.

5.3.1 Dynamic Simulation Parameter Setting

5.3.1.1 Trajectory Set

In Dynamic Simulation, we set the bottom of the slide way as the origin point. The distance of the bottom of guide rail to the floor is 310 mm (see Figure 5.3.1.1.1)
In the beginning, the distance from the origin point to the slide block is 250 mm (dynamic analysis coordinates) and the chair height is 364 mm (see Figures 5.3.1.1.2 & 5.3.1.1.3).

**Figure 5.3.1.1.2 Distance from point to slide block at beginning**

**Figure 5.3.1.1.3 Moment of seat height**
At the end, the distance from the origin point to the slide block is 550 mm (dynamic analysis coordinates), and the chair height is 664 mm. (see Figures 5.3.1.1.4 & 5.3.1.1.5)

Figure 5.3.1.1.4 Distance from point to slide block at ending

Figure 5.3.1.1.5 Moment of seat height

So the distance range from the seat to the floor is 364 mm to 664 mm.
5.3.1.2 External Load

The load force acting on the seat is shown below in Figure 5.3.1.2.1.

![External Load Diagram](image)

*Figure 5.3.1.2.1 External load*

5.3.1.3 Drive Set

We ran dynamic simulations to determine the drive force to choose the motor type. In order to calculate this, we considered that a constant moving speed for the chair is 5 mm/s. The relationship between the displacement and the simulation time when the slide block moves down or up was shown in Figure 5.3.1.3.1.
In Figure 5.3.1.3.2, the distance of the slide block moves from 250 mm to 550 mm. The seat can move 300 mm.
5.3.2 Calculations and Results

In this section we considered that the test person will sit on the chair. We simulated the chair sliding from the original position to the end point at a constant speed. After that we checked the driving force. This way, we can determine the critical driving force, and as a consequence, determine what kind of motor we will choose.

The seat slides from the original position (see Figure 5.3.2.1) until the ending position at a constant speed. The load is considered as a concentrated force of 850 N on the chair (see Figure 5.3.2.2). This load corresponds to the weight of a person weighing approximately 85 Kg.

The simulation time is 60 seconds.
By processing the data from the dynamic analysis, it was found that when the seat was moving up or down, the required driving force was constant. As the setting of speed was constant, and at the same time, there were no other external forces functioning when the seat was moving, it is firmly believe that the required driving force is 1121.81N when the seat is rising (or falling) in a straight line.
Figure 5.3.2.3 Drive Force when seat moves down

In Figure 5.3.2.4, the rolled ball screw shaft refers to an ideal product which is used for converting rotary motion into linear motion, or converting linear motion into rotary movement. Its function is to convert the rotary motion into linear motion.

Figure 5.3.2.4 The Rolled ball screw working
The Rolled Ball Screw’s data information from the NSK [28] and THK [29] Rolled Ball Screw’s Company in shown:
Rolled Ball Screw model: RNCT 1405A2.5S (Return tube type, square nut)

Figure 5.3.2.5 Rolled Ball Screws (Nut)

Figure 5.3.2.6 Rolled Ball Screws (Screw)

Figure 5.3.2.7 Mechanical Efficiency
From the Rolled Ball Screw model 1405A2.5S, it is known that:
The Diameter is the 14mm.
The lead is the 5 mm.
The Lead Angle can be calculated by using a formula

\[
\tan \beta = \frac{Ph}{\pi \cdot R} = \frac{5}{3.1415 \cdot 14} = 0.1137
\]

(5.15)

Where

<table>
<thead>
<tr>
<th>β</th>
<th>Lead angle</th>
<th>°</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>Diameter</td>
<td>mm</td>
</tr>
<tr>
<td>Ph</td>
<td>Lead</td>
<td>mm</td>
</tr>
</tbody>
</table>

After calculations the Lead Angle is

β=6.49

Most of the Rolling Guide is

μ=0.003

From Figure 5.3.2.7, one can get the forward efficiency (when rotate to linear)

\[
\eta = 0.96
\]

When the screw rotates, it produces thrust using the formula

\[
F = \frac{2\pi \cdot \eta \cdot T}{Ph}
\]

(5.16)
Where

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Driving force</td>
<td>N</td>
</tr>
<tr>
<td>T</td>
<td>Driving torque</td>
<td>N*mm</td>
</tr>
<tr>
<td>Ph</td>
<td>Lead</td>
<td>mm</td>
</tr>
<tr>
<td>η _f</td>
<td>Forward efficiency</td>
<td></td>
</tr>
</tbody>
</table>

Rewritten equation 5.16, using the driving torque is as follows:

\[ T = \frac{F \cdot Ph}{2\pi \cdot \eta} = \frac{1121.81N \cdot 5mm}{2 \cdot 3.1415 \cdot 0.96} = 929.93N \cdot mm \]
\[ = 0.93N \cdot m \]  
(5.17)

Mechanical equipment that can reach 100% mechanical efficiency does not exist, therefore the Driving Torque of the motor must be larger than 0.93Nmm.
6. ELETRIC CONTROL BOX

The electric control box (control system, Figure 7.1) is an automatic drive system, which connects the DC motor with the rolled ball screw to achieve vertical movement by electric control. The whole control box was personally manufactured ourselves. It is described in the following sections.

Figure 6.1 Electric control box

6.1 Components of Electric Control Box

This section will introduce the hardware of the control box, such as the DC regulated power supply, four-channel wireless receiver panel, PLC, DC motor, relay and so on.
6.1.1 DC Regulated Power Supply/ Converter

Figure 6.1.1.1 12V DC regulated power supply

Figure 6.1.1.2 24V DC regulated power supply

The DC regulated power supplies are made by MEAN WELL. Figure 6.1.1.1 shows a power supply which changes 220 volts AC (alternating current) into 12 volts DC. It is applied in the control system to deliver power to motors. Since the operating current is quite large, we selected a
DC regulated power supply with 22 ampere power output.

In Figure 6.1.1.2, it changes 220 volts AC into 24 voltages DC. It delivers direct current to a relay coil which uses 24 volts as the regular voltage.

6.1.2 Four-channel Wireless Receiver Panel

The four-channel wireless receiver panel with programmed command (Figure 6.1.2.1) receives a wireless remote control signal from a signal transmitter. In this case, the signal transmitter can send signals to the panel to control motors rotating clockwise or anti-clockwise.
6.1.3 Programmable Logic Controller

The programmable logic controller (figure 6.1.3.1) is produced by the company OMRON. It mainly operates the wireless signal from the four-channel wireless receiver panel, and issues commands to make contacts of relay coil to connect or disconnect to control DC motors to rotate clockwise, anti-clockwise and stop [30].

6.1.4 Push Button

Figure 6.1.4.1 Power button
A push-button switch with a ceramic actuator in this case is the power switch. When the button was pressed, the equipment would work, and wireless control would be effective.

### 6.1.5 Limit Switch

**Figure 6.1.5.1 Limit switch**
There are four limit switches (Figure 6.1.5.1) applied in four directions in this project, which are used for control of a motor, as safety interlocks, or to count objects passing a point. For instance, when an object passes the point that was arranged before, movements would be stopped at the same time. They connect with the input interface of PLC.

### 6.1.6 DC Motor Selection

The DC motor is the main power output of the electric control system, based on the driving torque calculated in the dynamic simulation. Selection of the DC motor was done step by step as follows.

As known, power is the main parameter for choosing a DC motor for the whole control system. And equation for calculating the real power is shown below:

\[
P_{\text{real}} = \frac{n_s T}{9549}
\]  

(6.1)
Table 6.1.6.1 Allowable torque on gearbox

<table>
<thead>
<tr>
<th>Model</th>
<th>Speed</th>
<th>Reduction Ratio</th>
<th>5</th>
<th>6</th>
<th>7.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDM-08SGN</td>
<td>rpm</td>
<td>Output Shaft Speed</td>
<td>r/min</td>
<td>360</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>1800</td>
<td>Allowable Torque</td>
<td>Nm</td>
<td>0.873</td>
<td>1.047</td>
</tr>
<tr>
<td>GDM-08SGN</td>
<td>rpm</td>
<td>Output Shaft Speed</td>
<td>r/min</td>
<td>640</td>
<td>533</td>
</tr>
<tr>
<td></td>
<td>3200</td>
<td>Allowable Torque</td>
<td>Nm</td>
<td>0.833</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Table 6.1.6.1 shows allowable torque of DC motors [31], it is quite easy to see that the parameters in the blue column are close to the driving torque in the dynamic simulation.

Driving torque from dynamic simulation is \( T = 0.93 \) Nm

Outer shaft speed, \( n = 1800/6 = 300 \) r/min

Service efficiency \( \eta_s = 0.8 \) was chosen in the normal situation.

From equation 6.1, once get real power \( P_{real} \)

\[
P_{real} = \frac{0.93 \times 0.8 \times 300}{9549} = 0.0234 \text{ kW} = 23 \text{ W}
\]

Table 6.1.6.2 Motor performance parameters

<table>
<thead>
<tr>
<th>Model</th>
<th>Voltage</th>
<th>Power</th>
<th>Load parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>V</td>
<td>W</td>
<td>Speed</td>
</tr>
<tr>
<td>GDM-08SGN</td>
<td>24</td>
<td>40</td>
<td>1800</td>
</tr>
<tr>
<td>GDM-08SGN</td>
<td>24</td>
<td>70</td>
<td>3200</td>
</tr>
</tbody>
</table>
Table 6.1.6.2 shows the performance parameters of the DC motor, and rated power $P_{\text{rated}}$ is 40 W with speed 1800 RPM which is shown in blue row [31].

Reasonably,

$$P_{\text{rated}} \cdot \eta_s > P_{\text{real}}$$  \hspace{1cm} (6.2)

From equation 6.2

$$P_{\text{rated}} \cdot \eta_s = 40 \cdot 0.8 = 32 \text{ W} > 23 \text{ W}$$

In conclusion, the DC motor - GDM-08SGN was selected with the parameters voltage 24 V, rated power 40 W, Speed 1800 RPM, and allowable torque 1.047 Nm. The reason for choosing a low speed motor is that lower speed leads to lower noise but higher power. And considering the whole working environment, a low speed DC motor is more suitable.

![Direct current motor](image)

*Figure 6.1.6.1 Direct current motor*

Since the whole system was applied in a damp environment, low voltage DC motors were selected because the safety was the most important factor
to be considered. The control circuit is easy for DC motor, and the motive capability is better than AC motor.

The DC motor produces the torque used for the power output on electric equipment. It is always the main power output device in the system. In this case, there are two motors applied in the system that move guide rail up and down, right and left respectively.

6.1.7 Relay

![Image of Relay](image)

Figure 6.1.7.1 Relay

The relay is an electrically operated switch, which is usually used in an automatic control circuit. Actually, it is an automatic switch that controls high voltage large currents with low voltage, and small currents. In this case, there are four relays (Figure 6.1.7.1) applied in the control box.
6.1.8 Signal Transmitter

![Signal transmitter](image)

*Figure 6.1.8.1 Signal transmitter for control box*

Signal transmitter (Figure 6.1.8.1), when the whole system is powered on, the controller could send a signal to a four-channel wireless receiver panel to control motors to work or not. It has four buttons which separately control these two motors rotating clockwise or anti-clockwise.

6.1.9 Control Panel

![Main control panel](image)

*Figure 6.1.9.1 Main control panel*
The power switch is the green buttons on the panel. When the power switch is pressed, the whole system works.

The emergency switch is the red button in Figure 6.1.9.1. As there may be an accident during the moving process. To be safe, the whole system can be stopped immediately by rotating the emergency button when an accident happens.

Indicators show the status of whole work system. When the green light is on, the system is working. On the contrary, when the red indicator light is on, the system is stopped.

Wiring hole, they two connect to DC motor.

**6.1.10 Backplane**

*Figure 6.1.10.1 Backplane of control box*

In Figure 6.1.10.1, the basic parameter of the backplane was shown by Autodesk Inventor. It is used to install most of the components of the control box, such as the PLC, PCB (Printed Circuit Board), the DC regulated power supply, the four-channel wireless receiver panel and relay.
6.1.11 Outer Shell of Electric Control Box

![Image of outer shell of control box]

*Figure 6.1.11.1 Outer shell of the control box*

Whether the outer shell box could be used in a different environment depends on the working properties. This box is called a waterproof instrument box which perfectly matches our safety concern. The basic measurements are 295 mm * 275 mm * 230 mm. Future AutoCAD designs would be carried out according to these measurements.

6.2 Circuit Design of Electric Control Box

This section includes software of the control box such as the circuits of control box, and working flow chart.
6.2.1 P134, Power Supply Terminal of Relay

This is a principle sheet made by PROTEL shown in Figure 6.2.1.1. P134 is a terminal block that not only delivers power to the relay but also gains the signal transmitted from PLC to control whether the relay coil is connected. RA1, RA2, RA3, RA4 were connected to relays.

24+ and 24- are two terminals connected with 24-volt voltage input.

6.2.2 7812, Voltage Regulator
7812 is a voltage regulator which converts 24 volt voltage into 12 volt voltage shown in Figure 6.2.2.1. In order to ensure the control system is stable and is not affected by the power system, the power circuit and the control circuit should definitely be separated. Pyk is a socket to deliver power to four-channel wireless receiver panel with 12 volt voltage. C2 is a capacitance for filtering.

### 6.2.3 P2, Power Supply Terminal of DC Motor

![Figure 6.2.3.1 Circuit of P2](image)

P2 is a terminal that delivers power to the DC motor. Contactors NET12+ and NET12- connect to relay contactors to provide power to the motor. Additionally, NetLabel28 and NetLabel29 are spare terminals for improvement or replacement.
6.2.4 P1, Connected Terminal

![Figure 6.2.4.1 Circuit of P1]

P1 is a terminal which connects with the relay coil contactors to control the DC motor rotating clockwise or counterclockwise. NetLabel30 and NetLabel31 are the utilized the same as NetLabel28 and NetLabel29 in previous articles.

6.2.5 MOTOR1 Component_1 and MOTOR2 Component_1

![Figure 6.2.5.1 Circuit of MOTOR1 Component_1]
Figure 6.2.5.2 Circuit of MOTOR2 Component_1

This is a basic principle picture of a relay. When loss of power happens on the relay coil electromotive force is generated, which would be assimilated by diode named D1 shown in figure 6.2.5.1 (MOTOR1 Component_1). A diode is a two-terminal electronic component with an asymmetric transfer characteristic, with low resistance to current flow in one direction, and high resistance in the other. The main function of a diode is to allow an electric current to pass through only in one direction, and the opposite is absolutely not allowed to pass. The situation of the relay shown in Figure 6.2.5.1 will not work when relay coil contactors 1 and 4 are connected. On the contrary, it will work while contactors 5 and 8 are connected. At the moment, the DC motor gains electric current to start rotating by wireless remote transmitter.

As shown in Figure 6.2.5.2 (MOTOR2 Component_1), these two figures have the same frame and arrangement. However, the relay is primarily applied for controlling the DC motor rotating clockwise or counterclockwise.
6.3 Working Flow Chart

Since the control box is defined as an electrical control system, there is a flow chart for the whole working system shown in the following Figure 6.3.1.

![Flow chart of a working system](image)

*Figure 6.3.1 Flow chart of a working system*

A description of the working system of the control box is described in the next paragraph and is based on Figure 6.3.1.

The working system starts with the power supply, through the DC-regulated power supply alternative current would be transformed into direct current immediately. 12 volt voltage delivers power to the DC motors and 24 volt
voltage was delivered to the relay coil at the same moment, respectively. Then, a signal is sent to the wireless receiver panel from signal transmitter. Following that, PLC receives an input signal from wireless receiver panel and issues command to control whether the relay coil is connected. Thus, the DC motors are commanded to start rotating with x-axis or y-axis direction that depends on a signal from a signal transmitter at first. Furthermore, a limit switch was applied to protect the safety of people who utilize the design. A boundary is established on the slider way to avoid accident damages for people and equipment.

6.4 Waterproof of the Control Box

In the electric control of the whole working system, waterproofing becomes a big challenge in this case since the control is to be installed in a wet environment. Several approaches have been considered on how and where to install the control box, as described in the following.

6.4.1 Brain Storming about Waterproof

A. Establish an isolation cover for whole control box and DC motor to achieve waterproofing. Install the control box under the moving chair.
B. Install the control box outside of the shower room, and set it above the door. And install the DC motor under the moving chair in the shower room, which connects with the control box through the door by a hole.
C. Install the control box above the moving chair, and make sure that it would not block the moving chair, also ensure it will not be wet by water.
D. Digging grooves on the door was considered since material of the
door is oak. As known, wood is easy to rebuild and carve.

6.4.2 Advantages and Disadvantages

a) Advantage of idea A is the concentration of component distribution, and it is easy to connect all of components. However, waterproofing of idea A is not safe enough due to the wet environment. It is required to be checked very often, which leads to waste of labor.

b) Advantage of idea B is that it is much safer than idea A, no more labor waste as well. Disadvantage is that the install location is far from the DC motor.

c) In idea C, the advantage is that the wiring system is easy to arrange, also the concentration of distribution. But, hot water vapor will raise high when people take a hot water shower. Water vapor aggregates into water drops when it meets the surface of the metal panel.

d) In idea D, an advantage is that wood is easy to carve, but waterproof ability of oak is terrible.

6.4.3 Conclusions on Waterproofing

These four ideas have been considered carefully, and the most important factor is safety. Thus, the selected standard is to judge which one is the safest among all four ideas. Idea B is obviously the safest and the most feasible approach, because the install location is out of shower room. It avoids water vapor meeting the electric control box. Fundamentally, it achieves waterproofing of the control box.
7. DISCUSSIONS AND CONCLUSIONS

In summary, to achieve the aim of making the shower as safe as possible, we decided to include automatic control of the moveable chair instead of manual control. We also did the following: An electric control box was manufactured for automatic control of the driving system; slide ways were selected for guiding the moveable chair; stress analyses were done under static conditions on the model of shower room; a dynamic analysis was done on the moving chair during the working procedure.

Figure 7.1 shows the bathroom after making the improvements in this thesis work. The main components which have been improved are the electric control box, moving chair, and slide ways.

![Figure 7.1 Bathroom after improvements](image)
7.1. The Door

Regarding the material selection, many kinds of materials are suitable for doors, although there are already some references, determining the specific types of materials was still hard, so a market survey was carried out. Firstly, materials for load-bearing door were researched on the Internet worldwide; secondly, a field survey of the sales market in Karlskrona (Sweden), Beijing and Shanghai (China) was undertaken; finally, four kinds of materials were identified. Then the mechanical properties and the prices of those materials were compared, and stainless steel was chosen as the primary material for door.

7.2. Static Simulation

While analyzing the static simulation, several problems were identified and needed to be conquered. Taking Model 1 as an example, after assembling Model 1, constraints were carefully applied to this model. Because there were many constraints, when one or several constraints were not correctly applied, the results obtained were wrong and were very different from the true value. Thus, when doing the static simulation of Model 1 and Model 2, Model 1 was set as a whole part, and so was Model 2. In this way, constraints were not a problem, the results obtained were really close to the true value, and they were good enough to analyze where the maximum Von Mises Stress appeared to help us to see where the weak part of the whole system was.

Instead of analyzing Model 1 or Model 2 as a whole part, assembling Model 1 and Model 2, and applying constraints to those models correctly, and then carrying out the static simulation would be the best way. The results would be more objective and closer to the true value. However, because too many constraints needed to be applied to those two models, we
gave up this method and chose a more simple way described in previous paragraph to accomplish our static simulation.

A problem also occurred when doing the static simulation of Model 2. While checking the maximum Von Mises Stress o Model 2, one of the screws which connect the door with the wall led to a plastic failure and we had to enlarge those screws to ensure that no plastic failure occurs.

### 7.3. Dynamic Analysis

In the dynamic analysis, several dynamic analyses were taken and the driving force turned out to be very large, around 500,000N. This result was far greater than the theoretical value. We then checked all design processes and dynamic parameter settings, and found out that the results were still not correct. Therefore, a re-assembling was carried out, the constraints were changed from two points in horizontal to three points in a plane, and the same parameters were set to conduct a dynamic simulation. The result was 1121.81N. This value is a little larger than the theoretical value. However, taking the frictional force and mechanical loss into account, the driving force of 1121.81N was credible.

### 7.4. Automatic Control Driving System

In order to establish an automatic control driving system with wireless control, a four-channel wireless receiver panel and PLC were carefully chosen with programmed products. Also DC motors with reduction ratio produced would be our choice. Attention to wiring among all components, and deviation needs to be considered before assembling.
7.5. Future research

- Horizontal movements of the chair
- Design of waterproofing improvements
- Improvements on other equipment in bathroom, like toilet.

7.6. Conclusions

In this study an analysis of a standard bathroom model was carried out and an optimized design was created to make the shower more convenient and safer for the elderly and disabled people.

Autodesk Inventor was used to carry out static and dynamic simulations to ensure functionality and safety of the moving chair and other components. PROTEL was used to sketch principle circuit sheets, and assembling them on the circuit board.

Our improvements are reliable, according to our results from manual calculation, static simulation, and dynamic analysis.

The main components of the bathroom which have been improved are the electric control box, moving chair, and slide ways. The electric control box was manufactured out as an automatic control driving system, which was applicable to connect with two DC motors to output power. It is stored in Shanghai Second Polytechnic University, Shanghai, China.
8. REFERENCES


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