Multi-functional fitness chair
for light weight trainer

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in cooperation with
Abstract

Nowadays, physical inactivity has become a global problem. According to the research, about 5.3 million deaths all over the world in 2008 could be attributed to inactivity [1]. However, it is enough to do a little exercise every day to reduce the risk of premature deaths by as much as 30 percent. Due to the increasing working pressure, people do not have enough time to go to gym and do exercises, which means that the design of multi-functional fitness chair is necessary so that people can do exercise at home at any time.

There have already been many similar household fitness products in the market, but most of them take up large space and the training part is very simple. In comparison, the multi-function fitness chair designed in this thesis combines several fitness equipment together in one chair, so it would save a lot of space, and yet provides possibility to perform versatile exercise.

The product was designed in Autodesk Inventor 2015, and finite element analysis was performed in Inventor 2015 and for checking the strength and safety of the design.

Keywords: Fitness chair, Multi-function fitness equipment, Enhanced access to fitness, Autodesk Inventor 2015, Finite Element Simulation.
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Fan Rong
Wu Peng
# Contents

Abstract .................................................................................................................. 3  
Acknowledgements ............................................................................................... 5  
Contents .................................................................................................................. 7  
List of figures ......................................................................................................... 10  
List of tables .......................................................................................................... 12  
List of symbols ....................................................................................................... 13  
List of acronyms .................................................................................................... 15  
1 Chapter: Introduction ....................................................................................... 17  
2 Chapter: Survey of related work ..................................................................... 19  
   2.1 Portable Sit-up Machine .............................................................................. 19  
   2.2 Rowing machine ......................................................................................... 20  
   2.3 Lat pull ......................................................................................................... 22  
   2.4 Leg extension ............................................................................................... 23  
   2.5 Existed multi-functional fitness chair- Peak Pilates MVe® Fitness Chair .................................................................................................................. 25  
   2.6 Summary ..................................................................................................... 26  
3 Chapter: Problem statement, objectives and main contribution .................. 28  
   3.1 Problem statement ...................................................................................... 28  
   3.2 Objectives and main contribution .............................................................. 28  
4 Chapter: Solution ............................................................................................... 30  
   4.1 Solution 1 .................................................................................................... 30  
   4.2 Solution 2 .................................................................................................... 31  
      4.2.1 The sleeve was replaced with the dual-shaft linear rail ....................... 31  
      4.2.2 The gears box to make the length of pulling rope and the deformation of springs different ................................................................. 32  
      4.2.3 Spring box ............................................................................................ 32  
      4.2.4 Ratchet .................................................................................................. 32  
      4.2.5 Sit-ups structure ................................................................................... 32  
5 Chapter: Details of the final solution ............................................................... 34  
   5.1 Design of the base ....................................................................................... 35  
   5.2 Design of the seat and the back ................................................................ 36  
   5.3 Design of the leg support .......................................................................... 37
5.4 The choose of the wire rope ............................................................ 39
5.5 Design of the spring box ................................................................. 40
5.6 Design of the connecting part of the spring .................................... 42
5.7 Design of the connecting part between the back and slider ............ 42
5.8 Design of the gears box ................................................................ 43
5.9 Dual-shaft linear rail .................................................................... 44
5.10 Cylinder-linear rail ..................................................................... 46
5.11 Ratchet and pawl ........................................................................ 47
  5.11.1 The design of ratchet gearing.................................................. 49
    5.11.1.1 The shape of the ratchet gearing......................................... 49
    5.11.1.2 The determination of module and number of teeth ............ 49
    5.11.1.3 The dimensions of the ratchet gearing................................ 49
5.12 Material choice ........................................................................... 51
6 Instruction....................................................................................... 54
  6.1 Abstract ........................................................................................ 54
  6.2 Product overview .......................................................................... 54
  6.3 Main exercises ............................................................................. 55
    6.3.1 Lat pull .................................................................................. 55
    6.3.2 Rowing exercise .................................................................... 56
    6.3.3 Leg extension ........................................................................ 57
    6.3.4 Sit-up exercise ....................................................................... 58
      6.3.4.1 Without weights ................................................................ 58
      6.3.4.2 With weights ................................................................... 59
  6.4 Extra exercises ............................................................................. 60
    6.4.1 Musculus Biceps Brachii Curl .................................................. 62
    6.4.2 Cable Pushdown .................................................................... 62
  6.5 Weights ...................................................................................... 63
7 Chapter: Hand calculation............................................................... 64
  7.1 Welding ....................................................................................... 64
  7.2 Gear calculation .......................................................................... 68
  7.3 Cylindrically helical tension spring design .................................... 73
  7.4 The choice of spring .................................................................... 76
8 Chapter: FEM simulation ................................................................. 77
  8.1 Welding simulation ..................................................................... 77
  8.2 Gear simulation .......................................................................... 78
  8.3 Spring simulation ........................................................................ 79
9 Chapter: Conclusion and future work ............................................ 81
Reference............................................................................................ 82
Appendix 1: ................................................................. 85
Drawing of the full equipment assembly ..................... 85
Appendix 2: ................................................................. 86
Drawing of main components ................................. 86
List of figures

Figure 1.1 Obesity in the UK [2] ................................................................. 17
Figure 2.1 Portable Sit-up Machine JS-060h [3] ........................................... 19
Figure 2.2 Different muscles in stomach [5] .............................................. 20
Figure 2.3 Rowing machine [6] ................................................................. 21
Figure 2.41 Start of the “Drive” [7] .............................................................. 21
Figure 2.52 The “Drive” [7] ..................................................................... 22
Figure 2.63 The “Finish” [7] .................................................................... 22
Figure 2.7 The training part of lat pull [8] .................................................. 23
Figure 2.8 Cybex VR1 Lateral Pulldown [9] .............................................. 23
Figure 2.9 Optima Series Leg Extension/Curl [10] ...................................... 24
Figure 2.10 Working muscle in leg extension [11] ..................................... 24
Figure 2.11 Peak Pilates MVe® Fitness Chair [12] .................................. 25
Figure 2.12 MVe Fitness Chair exercises [13] .......................................... 26
Figure 3.1 FW-188 household multi-functional fitness equipment [14] ...... 28
Figure 4.1 Previous product ..................................................................... 30
Figure 4.2 Sleeve slider ............................................................................. 31
Figure 4.3 Slider ....................................................................................... 32
Figure 5.1 Multi-Use Adjustable Dumbbell Chair [16] ............................ 35
Figure 5.2 The base of the chair ............................................................... 36
Figure 5.3 Gaming chair [17] .................................................................. 37
Figure 5.4 The seat and the back .............................................................. 37
Figure 5.5 Leg support ............................................................................. 38
Figure 5.6 GLCE365-Leg-Curl-Extension [18] .......................................... 38
Figure 5.7 SWR 7×19 wire rope [19] ....................................................... 39
Figure 5.8 Breaking load in different diameter [19] ................................... 39
Figure 5.9 Different types of the end terminations [19] ............................ 40
Figure 5.10 Design of the spring box ....................................................... 40
Figure 5.11 Whole view of spring box ...................................................... 41
Figure 5.12 Internal structure of the spring box ...................................... 41
Figure 5.13 The connecting of the spring ............................................... 42
Figure 5.14 Design of the connecting part of the spring ......................... 42
Figure 5.15 Design of the connecting part between the back and slider .... 43
Figure 5.16 The whole structure ............................................................. 43
Figure 5.17 Design of the gears box ....................................................... 44
Figure 5.18 Specification of external dual-shaft linear rail [20] ................. 45
Figure 5.19 The dual-shaft linear rail [20] ............................................. 45
Figure 5.20 The dual-shaft linear rail and the cylinder-linear rail ............ 46
Figure 5.21 Specification of cylinder-linear rail [20] ..................................... 47
Figure 5.22 Cylinder linear rail series [20] .................................................. 47
Figure 5.23 Internal ratchet gearing [22] ..................................................... 48
Figure 5.24 Different shapes of the ratchet gearing ..................................... 49
Figure 5.25 Design dimension of the ratchet gearing ................................... 50
Figure 5.26 Ratchet and pawl ..................................................................... 51
Figure 6.1 Components of the whole product ............................................. 54
Figure 6.2 Lat pull exercise ......................................................................... 56
Figure 6.3 Rowing exercise ......................................................................... 57
Figure 6.4 Leg extension ............................................................................ 58
Figure 6.5 Sit-up without weights ................................................................. 59
Figure 6.6 Sit-up with weights ..................................................................... 60
Figure 6.7 Musculus biceps brachii curl [24]h ........................................... 61
Figure 6.8 Cable Pushdown [25] ................................................................. 61
Figure 6.9 Musculus biceps brachii curl ..................................................... 62
Figure 6.10 Cable Pushdown ...................................................................... 63
Figure 7.1 Structure of welding .................................................................. 65
Figure 7.2 Parameters of the gears [27] ...................................................... 73
Figure 7.3 Mechanical properties of 65Mn [28] ......................................... 74
Figure 7.4 Types of the spring [29] ............................................................... 76
Figure 8.1 Welding function in Inventor ....................................................... 77
Figure 8.2 Welding stress ........................................................................... 78
Figure 8.3 Gear stress ................................................................................ 79
Figure 8.4 The deflection of the spring by 100 N ....................................... 79
Figure 8.5 The deflection of the spring by 150 N ....................................... 80
List of tables

Table 2-1 Different working muscles in different exercises .................. 26
Table 5-1 Lists of main parts ................................................................. 34
Table 5-2 Datum of the fitness chair [16] .............................................. 35
Table 5-3 Assessment of the type .......................................................... 36
Table 5-4 Dimensions of the ratchet gearing ......................................... 50
Table 5-5 Mechanical Properties of Aluminum 6061-T4 [23] ................. 51
Table 7-1 Known datum of gears ............................................................ 68
Table 7-2 Main parameter of different springs ...................................... 76
Table 8-1 The deflection at ultimate load for different types of spring ....... 79
### List of symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Quantity</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m$</td>
<td>Module</td>
<td></td>
</tr>
<tr>
<td>$Z$</td>
<td>Number of teeth</td>
<td></td>
</tr>
<tr>
<td>$d_a$</td>
<td>Tip diameter</td>
<td>mm</td>
</tr>
<tr>
<td>$p$</td>
<td>Circular pitch</td>
<td>mm</td>
</tr>
<tr>
<td>$h$</td>
<td>Tooth height</td>
<td>mm</td>
</tr>
<tr>
<td>$a_1$</td>
<td>Working length of the pawl</td>
<td>mm</td>
</tr>
<tr>
<td>$b$</td>
<td>Width of the ratchet</td>
<td>mm</td>
</tr>
<tr>
<td>$h_1$</td>
<td>Tooth slant</td>
<td>mm</td>
</tr>
<tr>
<td>$r_f$</td>
<td>Ratchet dedendum circle radius</td>
<td>mm</td>
</tr>
<tr>
<td>$r_1$</td>
<td>Ratchet addendum circle radius</td>
<td>mm</td>
</tr>
<tr>
<td>$L$</td>
<td>The length of the pawl</td>
<td>mm</td>
</tr>
<tr>
<td>$r_1$</td>
<td>Ratchet addendum circle radius</td>
<td>mm</td>
</tr>
<tr>
<td>$L$</td>
<td>The length of the pawl</td>
<td>mm</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Stress</td>
<td>Pa</td>
</tr>
<tr>
<td>$I$</td>
<td>Moment of inertia</td>
<td>$m^4$</td>
</tr>
<tr>
<td>$C$</td>
<td>Spring index</td>
<td></td>
</tr>
<tr>
<td>$d$</td>
<td>Diameter of wire</td>
<td>mm</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Deflection at ultimate load</td>
<td>mm</td>
</tr>
<tr>
<td>$\tau_{max}$</td>
<td>Maximum cyclic shear stress</td>
<td>MPa</td>
</tr>
<tr>
<td>$S_{ca}$</td>
<td>Fatigue strength safety factor</td>
<td></td>
</tr>
<tr>
<td>$\tau_0$</td>
<td>Pulsating cyclic shear fatigue limit of the spring material</td>
<td>MPa</td>
</tr>
<tr>
<td>$S_F$</td>
<td>Design safety factor of fatigue strength of the spring</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>---------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>$P$</td>
<td>Input power</td>
<td></td>
</tr>
<tr>
<td>$n_1$</td>
<td>Pinion speed</td>
<td></td>
</tr>
<tr>
<td>$u$</td>
<td>Gear ratio</td>
<td></td>
</tr>
<tr>
<td>$K_t$</td>
<td>Load factor</td>
<td></td>
</tr>
<tr>
<td>$T_1$</td>
<td>Torque of the pinion</td>
<td></td>
</tr>
<tr>
<td>$\phi_d$</td>
<td>Tooth width coefficient</td>
<td></td>
</tr>
<tr>
<td>$Z_E$</td>
<td>Material influence coefficient</td>
<td></td>
</tr>
<tr>
<td>$\sigma_{H_{lim1}}$</td>
<td>Fatigue strength limit of the pinion</td>
<td></td>
</tr>
<tr>
<td>$\sigma_{H_{lim2}}$</td>
<td>Fatigue strength limit of the wheel</td>
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</tr>
<tr>
<td>$K_{H\Delta1}$</td>
<td>Contact fatigue life factor</td>
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</tr>
<tr>
<td>$v_0$</td>
<td>Circumferential speed</td>
<td></td>
</tr>
<tr>
<td>$b$</td>
<td>Face width</td>
<td></td>
</tr>
<tr>
<td>$h_a^*$</td>
<td>Addendum Coefficient</td>
<td></td>
</tr>
<tr>
<td>$h_f$</td>
<td>Dedendum</td>
<td></td>
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</table>

- $P$: KW
- $n_1$: r/min
- $u$: 
- $K_t$: 
- $T_1$: N · mm
- $\phi_d$: 
- $Z_E$: MPa$^{\frac{1}{2}}$
- $\sigma_{H_{lim1}}$: MPa
- $\sigma_{H_{lim2}}$: MPa
- $K_{H\Delta1}$: 
- $v_0$: m/s
- $b$: mm
- $h_a^*$: 
- $h_f$: mm
## List of acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Unfolding</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEM</td>
<td>Finite Element Method</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer aided design</td>
</tr>
</tbody>
</table>
Chapter: Introduction

With the development of the society, our living condition is much more comfortable than before. However the good condition also bring a lot of health problem, on the other word, lacking exercise can cause many chronic diseases [1]. Except the elderly, more and more young people are suffering from sub health problems. As for the students, the lack of exercise bring about the descending of the students’ body ability, and they are more likely to get sick. According to the research, overall 64% of adults in the UK are overweight or obese, with a Body Mass Index of 25 or over. Around 8% of deaths are attributed to obesity related illness in the UK [2].

As for the office workers, having Irregular diet and life pressure also overload their body. When young people realize their health problems, they start to go to the gym or buy lots of fitness equipment in order to start exercising. Although there are many people doing exercise, most of them only last for few months. Besides, they may have difficulties which may interfere with them. For the students, they may not afford to go to the gym. And for the workers, their schedule always changed which may disrupt their plan of doing exercise, and after finishing the busy work, many people prefer to go home to have a rest than going to the gym. Thus there are few people insist on doing sports every day.
Besides if people choose to buy lots of fitness equipment to do sports at home, the equipment may occupy a lot of space and spend a lot of money.

Therefore, in order to solve these issues, our group attempt to design a chair which aims to get a full body workout by spending the least amount of money, it can exercise the waists, legs, shoulders and other parts of the body only by using this chair wherever you like. We think that the exercise intensity is more suitable to the young people, and they may occupy less space and cost less money.
2 Chapter: Survey of related work

2.1 Portable Sit-up Machine

For sitting in a chair for a long time, most of office workers have the lumbar spine (lower back), besides that, more and more people are facing too much pressure in the work, mostly having no time to have a healthy diet, sometimes even eating unhealthy food like some fast food. The Portable Sit-up Machine JS-060h [3] aims to help people having waist and abdomen exercises. From the training point of view, the training effect of this Sit-up machine is limited, because the back of the chair restores the original position only by the restoring force of the spring. However, using this equipment can exactly reduce the back pressure after a long time sitting. On the contrary, if the back can have an opposite movement direction, like the training equipment in the gym, in this way, people can training their waist and abdomen.

![Portable Sit-up Machine JS-060h](image)

_Nowadays, more and more people begin to do sit-up, in order to exercise the abdominal muscles. Mr. Olympia Arnold Schwarzenegger, a professional bodybuilder recommends people to do sit-up exercises, because through the sit-up exercise, it can strengthen the core and stabilizing muscles [4].

The primary muscle targeted in a pull up is Rectus Abdominis. The rectus abdominis can be said to be the wall of the abdominal muscles and are paired long muscles which connect the lower rib cage and the hips. It also creates six_
pack effect. The functions of these muscles are tensing the abdominal wall, flexing the trunk and stabilize the pelvis [5]. Doing sit-up exercise can also exercise External Oblique, which attach to the rib cage and the pelvis. In addition, Tensor Fasciae Latae and Rectus Femoris can also be exercised during the sit-up exercise.

Figure 2.2 Different muscles in stomach [5]

2.2 Rowing machine

One of the best amenities in the gym is the rowing machine. Modelo D, a rowing machine [6], you can exercise different parts of your body in different posture. It can not only works on the upper body, but also works on the lower body, besides that, it can also exercise your abdominal muscle. For example, when it works on the upper body, 75 percent of the power comes from your legs and hips. In this way, you can tone your legs and firm your thighs, as long as you row properly and regularly. The rowing machine is good way to improve cardiovascular fitness.
There are many reasons that people are choosing to do indoor exercises by the rowing machine. The first one is people in different ages can use rowing machine, it was designed to bring benefits to the masses. The second reason is it can train the total body, not only for the upper-body, but also for the lower-body, the rowing machine gets nine major muscle groups worked such as quads, core, shoulders, back, hamstrings and so on. The third reason is it is an effective aerobic exercise, no matter what the age is, aerobic exercise is one of the most important contributor to the total health, for instance, a regular aerobic exercise can make the immune system stronger than before. And the last reason is it is easy to learn, a basic rowing exercise can be learned in 10 minutes or less.

A basic rowing exercise can be divided into three process, and in different process, the working muscles are also different [7].

1. Start of the “Drive”

In this process, the working muscles are Erector, Spinae, Rhomboids, Quadriceps, Gastrocnemius and Soleus, and Hamstrings.

2. The “Drive”

In this process, the working muscles are Erector Spinae, Rectus Abdominis, Triceps, Rhomboids, Deltoids, Trapezius, Pectoralis Major, Wrist Extensors and Flexors, Quadriceps, Glutes, Hamstrings, and Gastrocnemius and Soleus.
3. The “Finish”

In this process, the working muscles are Erector Spinae, Wrist Extensors and Flexors, Triceps, Biceps, Deltoids, Pectoralis Major, Rectus Abdominis, Internal and External Oblique, Quadriceps, and Hamstrings.

2.3 Lat pull

The lat pull machine is very common in the gym, this equipment can be used for training biceps and shoulders, and this is also an effective exercise to make the muscle support the shoulder joint stronger, in addition, it is important to reduce sports-related injuries. The first step is adjusting user's sitting posture, the second step is grasping the bar which is wider than the shoulder width. Then slowly pull the bar down to the upper chest. When finished, slowly stand up and allow the weight stack to return. During the whole exercise process, the major working muscles are, Latissimus Dorsi, Teres major, Sternal portion of pectoralis major, Pectoralis minor, Rhomboids, and Biceps.
We have done some investigate on the internet, lots of lat pull machines are designed for the gym, because all of them need a large space, like one of the lat pull machine, Cybex VR1 Lateral Pulldown, a professional training machine, the dimensions of this machine is width 1223 mm, length 1901 mm, height 2201 mm [9].

2.4 Leg extension

The leg extension is a relatively simple exercise, which works at only one joint, so it means it is a basic and limited motion. Sitting on the machine with the knees at a 90 degree angle and the back should be straight, lifting the weight until the legs are almost straight, however, in the whole exercise, the knees
should be kept a slight bend in order to protect the joint from excessive wear and tear. The simplicity of the leg extension makes it easy to learn.

Figure 2.9 Optima Series Leg Extension/Curl [10]

The exercise of leg extension is a key exercise in strengthening the patellar ligament and the quadriceps attachment for the knees, so the leg extension machines are very common in the gym. Optima Series Leg Extension/Curl is a professional machine which for the leg extension. The primary muscle targeted in a pull up is Quadriceps.

Figure 2.10 Working muscle in leg extension [11]

The correct leg extension form.
1. Sit on the leg extension machine and keep the back straight, it means the back should stick to the back of chair throughout the whole movement.
2. Adjust the pedal above the feet and much below the knees, which should be comfortable and appropriate.
3. Adjust the weight which is suitable to the trainer.
4. Start to raise legs and halt just before the legs are straight, the whole movement should be slowly, otherwise it will do damage to the knees.
5. Squeeze the quadriceps for a second slowly bring down the legs and stop just before the knees are perpendicular.
6. Do 3-4 sets with 10-15 repetitions each.

2.5 Existed multi-functional fitness chair- Peak Pilates

MVe® Fitness Chair

Pilates chair is an existed professional chair for fitness, it is sleek and metal, stable, portable and stackable which up to 5 for high for space saving. This chair can be folded and easily fits into a closet, under the bed or put into a car.

![Figure 2.11 Peak Pilates MVe® Fitness Chair](image)

The Pilates chair is lightweight, but solidly built and is suitable for all body sizes. The function of the Pilates fitness chair is, sculpting legs, arms, buttocks, thighs and other parts of body, so this chair is ideal for one on one training or some small group classes. The MVe fitness chair facilitates the performance of
many Pilates exercises, the following figure is some of the MVe fitness chair exercises.

Figure 2.12 MVe Fitness Chair exercises [13]

A group of researchers have done a research and the objectives of the research is to assess the feasibility and efficacy of delivering Pilates exercises for resistance training to breast cancer survivors using the MVe Fitness Chair. Twenty-six female breast cancer survivors were invited to participate in this research, and the result shows that the MVe Fitness Chair is feasible for use in breast cancer survivors [13].

2.6 Summary

Table 2-1 Different working muscles in different exercises

<table>
<thead>
<tr>
<th>Fitness machine</th>
<th>Working muscles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sit-up Machine</td>
<td>Rectus Abdominis</td>
</tr>
<tr>
<td></td>
<td>External Oblique</td>
</tr>
<tr>
<td></td>
<td>Tensor Fasciae Late</td>
</tr>
<tr>
<td></td>
<td>Rectus Femoris</td>
</tr>
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26
<table>
<thead>
<tr>
<th>Machine</th>
<th>Muscles Involved</th>
</tr>
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<tbody>
<tr>
<td>Rowing machine</td>
<td>Erector, Spinac, Rhomboids, Quadriceps, Gastrocenisius and Soleus, Hamstrings,</td>
</tr>
<tr>
<td></td>
<td>Trapezius, Pectoralis Major, Wrist Extensors and Flexors.</td>
</tr>
<tr>
<td>Lat pull</td>
<td>Latissimus Dorsi, Teres major, Sternal portion of pectoralis major,</td>
</tr>
<tr>
<td></td>
<td>Pectoralis minor, Rhomboids, Biceps.</td>
</tr>
<tr>
<td>Leg extension</td>
<td>Quadriceps</td>
</tr>
</tbody>
</table>
3 Chapter: Problem statement, objectives and main contribution

3.1 Problem statement

In the market, varieties of household fitness equipment have already existed, however most of them have a same problem, taking a lot of space. For instance, FW-188 multi-functional fitness equipment, a household fitness equipment, a complete set of equipment take a large space [14]. The average floor area per capita in Sweden in 2008 is $58m^2/cap$ [15]. It means, in most situation, there are not a lot of space to place household fitness equipment, besides that, the training part is very simple, one equipment corresponds to a certain training part.

![Figure 3.1 FW-188 household multi-functional fitness equipment [14]](image)

In our design, we combine several kinds of fitness equipment together in one chair, in this way, we can save a lot of space, to most family it is a good choice.

3.2 Objectives and main contribution

According to the previous part, we can conclude that there is a contradictory point in the household fitness equipment field, a professional household fitness
equipment need to take a lot of space, on the contrary, a simple, normal household fitness equipment is small, however only can training several parts of bodies. A number of people think, training the same parts of body every day is more efficient. This is one of the worst exercise mistakes, these mistakes are destroying bodies’ metabolism, keeping flabby, weak and injury-prone. Human are creatures of habit and tend to stick to things which are familiar with and good at. But when it comes to the training, people should keep changing training parts if the trainer what to make progress, in this way, it can keep metabolism running on high.

So our group want to design a household multi-functional fitness chair for the people who wants to have light weight training to keep fit at home or for some fitness training beginners. This kind of household multi-functional fitness chair combines with a variety of fitness equipment, so it only takes a little space.

Since this product is designed for light weight training, so there is no need to use barbell weights to provide force, we want to use springs instead of dumbbell weights, this is an efficient way to deduce the probability of the accident happens, which hit by a dumbbell, besides it can also save space.
4 Chapter: Solution

4.1 Solution1

Figure 4.1 Previous product

In the preliminary design, it has not enough functions and useless structures.

This fitness chair used common chair with the spring structure providing force for sit-up exercise and leg rod setting on the front of the chair for leg extension. The structure has been shown in the Figure 4.1.

The advantage of the design is that it is lighter than these in the gym. Moreover, it can be used in the office or some small space. Users just lay on the back of the chair to do some exercises instead of going to the gym.

However, it is limited in the function and effect. What is more important, it is difficult to combine the fitness parts with the part which provides forces. And then, in that part which provides forces, it is lack of the up and down stability because the wheels were not fixed on the ground. When doing sit-up exercise, it is easy to find that users cannot exercise the abdominal muscles because they do not use the power of the waist completely but the back power.
4.2 Solution 2

According to disadvantage the preliminary design and multifunction, an innovation design was come up with. It also depends the spring structure to provide different forces for fitness exercises. In order to solving the lack of the stability in the spring part which provides force, the liner rails replace wheels and it more stable than the past in the structure. It will be shown in the Figure 33.

What is more, some other function for fitness has been added to this design, for example, lat pull, rolling exercise, musculus biceps brachii curl and table pushdown. The instruction for using will been shown in the next literature. After discussing, this design was adopted.

4.2.1 The sleeve was replaced with the dual-shaft linear rail

However, there are some problems in the structure. When doing rolling exercise, the seat must be moved forth and back with the body of user but here it just was fitted over the bar of the chair holder by sleeve. It can cause wear between sleeve and that bar and reduction of the product durability. According to this reason, the dual-shaft linear rail should be the best choice.

![Figure 4.2 Sleeve slider](image-url)
4.2.2 The gears box to make the length of pulling rope and the deformation of springs different

Because of using the same kind of springs to output different forces, a problem, that the deformation of springs is limited in a small range but the length of pulling rope is larger, must be considered. In order to achieve this goal, the gears box was designed after brainstorming.

4.2.3 Spring box

The different user needs different weights while doing exercises so here are 2 kinds of springs. The issue is how to link these springs on the fitness structures. Under such conditions, the spring box was designed.

In this design, it also solves the swing up and down of springs.

4.2.4 Ratchet

Here, the back must be disconnected with the spring structure and fixed at a certain angle while doing other exercises except sit-ups. In this design, the ratchet is inserted into the back and combined with the seat.

4.2.5 Sit-ups structure

In previous design, the user lies on the back and pushes the back which connects with the spring structure to do sit-ups. After investigating the gym, some people suggest that the abdominal muscle are tight when doing Sit-ups.
but it does not in that way. According to some other ways to do Sit-ups, the new method was gotten.

In this solution, feet must be fixed on somewhere so the pedal to set feet on is added.
5 Chapter: Chapter: 
Details of the final solution

After the group meeting and brainstorming, the product have been added more fitness function on it. For example the sit-up exercise, lat pull, leg extension, rowing exercise and some other exercises. The product can be roughly divided into several main parts, and the following table 5-1 is the lists of them.

*Table 5-1 Lists of main parts*

<table>
<thead>
<tr>
<th>Part number</th>
<th>Name</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Seat and back</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Leg support</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Telescopic rod</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Ratchet and pawl</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>Linear rail</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>Rocker mechanism</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Gears box</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Spring box</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>Leg fixing rod</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>Cylinder-linear rail</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>Dual-shaft linear rail</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>Slider</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>Chair handle</td>
<td>1</td>
</tr>
</tbody>
</table>
5.1 Design of the base

It is similar to some existed fitness chair, the most important factor of the base is strength. In order to make the base have a higher strength, two crossbeams are added to the front and back of the base, besides, at the both sides of the crossbeams, there are four anti-skid pads. One function of the anti-skid pads is increasing the friction force between the crossbeams and the floor, and the other function is reduce the damage to the floor, the main material of the fitness chair is carbon steel, the whole weight of the chair is a big force, which is exerted to the floor, this might do damage to the floor, that is why we add four anti-skid pads.

In order to estimate the possible prize of the product, we investigated some similar items on the internet.

![Multi-Use Adjustable Dumbbell Chair](image)

**Figure 5.1 Multi-Use Adjustable Dumbbell Chair [16]**

**Table 5-2 Datum of the fitness chair [16]**

<table>
<thead>
<tr>
<th>Price</th>
<th>Size</th>
<th>weight</th>
</tr>
</thead>
</table>
| $ 170 | Length: 1300 mm  
Width: 320 mm  
Height: 800 mm | 150 kg |
5.2 Design of the seat and the back

Before the design of the seat and the back, our group have a discussion about how the seat and the chair like, there are two different choices, one is the common shape of the seat and the back, like the exercise chair in the gym, and the other is gaming chair, it is known to us that the gaming chair is designed for the E-sport match, and be famous for its comfort, one of the group member explain why he wants to design the back and the seat base on the gaming chair, no one is willing to treat exercise as a burden, using a comfortable chair is more likely to reduce the exhaustion after finish exercises. Then our group have a brainstorm, which aims to find a proper solution.

Table 5-3 Assessment of the type

<table>
<thead>
<tr>
<th>Type</th>
<th>Economy</th>
<th>Safety</th>
<th>Comfort</th>
<th>Design</th>
<th>Practicability</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercise chair</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Gaming chair</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>

After the brainstorm, we decide to design the seat and the back like a traditional exercise chair. From the table we can find that the weakest point is the comfort, so we want to do some improvements to the back and the seat, choosing soft material like sponge, and also thicken the seat and the back, make it more comfortable and softer, in this way, it is suitable for long-time exercise.
5.3 Design of the leg support

The leg support is one of training part in our design, and it has two functions. The first one is having leg extension exercises. There is a hook, which can connect with a wire rope, and at the other side of the rope is the spring. Springs are the source of the force, when the trainer having leg extension exercise, he needs to put the leg under the pedal of the support, in order to make it more comfortable, there are also two sponges around the support, then start to raise legs and halt just before the legs are straight, during the whole process, the leg support stretch the springs by the wire rope, it will be introduced in the next
part. The second function of the leg support is the base of long pole, this part will be introduced in the next part.

Figure 5.5 Leg support

The design of the leg extension part comes from this product. However there are also some disadvantages. In this product, the source of the force is the barbell weights. In order to have different forces, different sizes of the barbell weights are needed, and they may take too much space. Another disadvantage is that people have difficulty in replacing the barbell weights. Comparing to the spring, we find that changing springs is much easier, people can just by hanging up another spring.

Figure 5.6 GLCE365-Leg-Curl-Extension [18]
5.4 The choose of the wire rope

The wire rope is a type of cable which consists of several strands of material wire twisted into a helix, it is one of the most important component in the product, because the strength of the wire rope determine whether the product is safe or not. After having a serious of research, both the strength and the price of the wire rope in different companies, finally the wire rope made in SWR is chosen. First of all, the type of cross-sectional should be decided, $7 \times 19$ is very popular in diameters from 3mm to 16mm, and is used on a variety of applications, especially being used in the gym equipment as it has a very tough coating. The following figure shows the breaking load in different diameter.

![Figure 5.7 SWR 7×19 wire rope [19]](image)

<table>
<thead>
<tr>
<th>Nominal Diameter</th>
<th>Approximate Mass (kg/mm)</th>
<th>Minimum breaking load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 mm</td>
<td>0.034</td>
<td>6.17</td>
</tr>
<tr>
<td>4 mm</td>
<td>0.061</td>
<td>10.38</td>
</tr>
<tr>
<td>5 mm</td>
<td>0.096</td>
<td>16.02</td>
</tr>
<tr>
<td>6 mm</td>
<td>0.137</td>
<td>23.07</td>
</tr>
<tr>
<td>7 mm</td>
<td>0.187</td>
<td>31.49</td>
</tr>
<tr>
<td>8 mm</td>
<td>0.264</td>
<td>41.31</td>
</tr>
</tbody>
</table>

![Figure 5.8 Breaking load in different diameter [19]](image)

Finally, a 4mm 7x19 Galvanised Wire Rope coated to 5mm in Clear Nylon is chosen for the product. Besides, the end terminations for the wire rope should also be chosen, otherwise, there is no place to connect the wire rope and the hook.
After having a look about the wire rope in the gym, it is found that the Thimble Eye is more common in the gym, so the end terminations have been chosen.

### 5.5 Design of the spring box

In order to make the product lighter and simpler than those equipment in the gym, the chair uses springs instead of the dumbbell weights to provide forces which the user needs to achieve fitness effect as can be seen in the Figure 5.10

Moreover, the function of this fitness chair is 6 in 1, it means springs must output different weights when doing exercises. Actually, when doing exercises for different parts of the body, it needs different weights.

On the other hand, different people need different weights. However, according to the calculation and analysis, if only using one group of springs with the same spring constant and sizes, it cannot output different forces.

Now, 4 kinds of springs are selected to solve it. Thus, the aim is to make a design springs box to set springs and let springs output different forces as can be seen in the Figure 5.11.
There is a slide way to fix the end of spring on the front plate. For example, setting the slider which is fixed with the end of spring into the slide way from the bigger central hole and drive it to the fixed point above the hole along the slide way.

In order to reduce the spring swing up and down while pulling springs, it is necessary to design a pipeline to reduce the swing in the box, which can be seen in the Figure 5.12. There needs 4 spring boxes and it depends on how many springs there is.

Here it is necessary to point out that each kind of spring is made up in groups of 4 or 2. In this way, providing different forces. Showing at following Figure 5.13.
5.6 Design of the connecting part of the spring

On the other end of the spring, it is fixed on the other slider which can insert into the sleeve around the shaft of the connecting rod. In previous ideas, this connecting rod was fixed on the two wheels but it will move up and down when pulling it. After a further brainstorming, a better method is found to optimize the production and the modification can be seen in the Figure 5.14. Here are 2 cylinder-linear rails to instead of wheels to limit 2 degree of freedoms up and down. Let the connecting rod be fixed on the slide moving on the rail. Thus it can achieve the purpose to pull springs.

5.7 Design of the connecting part between the back and slider

On the multi-functional fitness chair, every part must be fully used. For instance, when doing sit-up exercise, the seat back is used as can be seen in the Figure-5.16.
Due to only one outputting-forces point, the way to connect the back and springs is more important. Firstly, design a curved connecting rod to make the seat back rotate around the shaft and the other end of the rod is fixed on the slider that slide on the rail fixed on the incline beam of the chair frame. Besides, the bottom of the slider is connected with springs by connecting rod. The detail of this part design has been shown in the following Figure-5.16.

5.8 Design of the gears box

At the beginning of design, this part was not come up but some problem was found when designing spring. Normally, when doing lat pull exercise, the length of pulling the rope is half a meter as long as the deformation of springs. However, according to the measurement and actual research, the deformation
of spring is less than half a meter. In this case, the gears box is designed as is shown in the Figure-5.17.

![Figure 5.17 Design of the gears box](image)

Here two gears whose drive ratio is 2 are used. The bigger one connects the wire rope and smaller one connects the springs. Thus, if rope is pulled half a meter, the deformation of springs is a quarter meters.

### 5.9 Dual-shaft linear rail

Two dual-shaft linear rails are used in the base of the chair. These two dual-shaft linear rails have the same functions but are installed in different places, one is connected with the seat, due to the rowing exercise, the seat should move smoothly. Another place using a dual-shaft linear rail is the slider, it can said that the slider is the most important part in the whole equipment, the friction between the slider and base of the chair should as small as possible, otherwise, it will affect the fitness effect. Thus using dual-shaft-linear rails are necessary. In the next part, we will introduce the superiority of dual-shaft linear rail and the specification of external dual-shaft linear rail.

Using dual-shaft linear rail has many advantages. For its high precision, the repetition error can be within three microns. The speed of the dual-shaft linear rail is five times faster than other existing products and with a lower noise. For its high resistance to grinding, the surface of steel shaft is hardened to greatly improve resistance to wear due to grinding. In addition, the dual-shaft linear
rail has the same quality of other linear rail but at lower price. Generally speaking, the dual-shaft linear rail are always used in laser machine industry, industrial machinery and some other high-speed transportation equipment.

| Model No. | H | W | L | H1 | L2 | P | D | Mr (g/m) | ml | m | W | H | L | L3 | T3 | B | L1 | S | BL (N) | DT (N-m) | Mb (g*pcs) |
|-----------|---|---|---|----|----|---|---|---------|----|---|---|---|---|----|----|---|---|---|---|-------|---------|----------|
| OSG-10N   | 18| 86| 50| 11 | 5.5| 60| 5 | 1760    | 0.5| 5.5| 81 | 8 | 80| 10 | 72 | 44| 440| 420| 20.6 | 33.9 | 34.2 | 140 |
| OSG-15    | 28| 62| 20| 15 | 5.5| 60| 6 | 1320    | 0.5| 5.5| 62 | 22.5| 60| 10 | 38 | 38| M5 | 700| 600| 23.0 | 33.4 | 35.4 | 120 |
| OSG-20    | 30| 62| 20| 20 | 5.5| 60| 6 | 1250    | 0.5| 5.5| 62 | 22.5| 60| 10 | 38 | 38| M5 | 700| 600| 23.0 | 33.4 | 35.4 | 120 |
| OSG-25    | 35| 80| 30| 21 | 0.5| 60| 8 | 1200    | 11 | 6.5| 80 | 12 | 80| 10 | 51 | 51| M3 | 1000| 95.2| 95.2 | 03 | 240 |
| OSG-30    | 40| 100| 36| 25 | 6.5| 60| 10| 3978    | 11 | 6.5| 100| 16.5| 100| 10 | 61 | 61| M6 | 3800| 2200| 72.5 | 72.5 | 147.8 | 520 |
| OSG-40    | 50| 130| 47| 31 | 5.8.5| 60| 12| 5212    | 14 | 9 | 130| 18| 130| 10 | 84 | 84| M6 | 4000| 4000| 448 | 448 | 448 | 113 |

Figure 5.18 Specification of external dual-shaft linear rail [20]

Figure 5.19 The dual-shaft linear rail [20]

The source of the table and the figure is from the Shenzhen Enkel technology co., LTD in China, this company is expertized in R&D, manufacturing and
selling of linear guide rails and other components for industrial motion application. According to the parameters in the table, we choose the model OSG-10N, and the sketch of the dual-shaft linear rail in Inventor is totally followed with the figure 5-20.

![Figure 5.20 The dual-shaft linear rail and the cylinder-linear rail](image)

5.10 Cylinder-linear rail

Similarly, the cylinder-linear rail is used support and guide moving parts, doing reciprocating linear motion in a given direction. Meanwhile, reaching a high positioning accuracy.

The cylinder-linear rail is used at the bottom base of the chair, which connected with a connecting rod, and the springs can be hanged on this connecting rod, the function of the cylinder-linear rail is to guide the springs moving in the horizontal direction.

We also choose the cylinder-linear rail manufactured by the Shenzhen Enkel technology co., LTD.
The model we choose is SBR20SA, the dimensions of SBR20SA are showed in the figure 5.21.

### 5.11 Ratchet and pawl

When having different exercises, there have different requirements of angle to the chair back. For example, during the lat pull, the back of the chair should...
have a certain angle. However, to different people, this certain angle is different from person to person. Compare to the lat pull, throughout the whole process of leg extension, the back of the chair should keep straight all the time, otherwise it will do damage to the knees. In this case, we need to find a way to fix the back of the chair. The back of the chair can have different angles and more important, it cannot rotate backward. The chair which is used in Roller Coaster inspired us, then we search for the principle of it. Finally we decide to use ratchet gearing to fix the back of the chair.

Ratchet and pawl is an intermittent motion mechanism, which consists of rocker, pawl and external ratchet. The function of the ratchet gearing is to prevent the ratchet wheel from rotating backward. The ratchet is widely used in many mechanical equipment, one of the most common product is the ratcheting socket wrench.

Ratchet gearing has many different types. Due to the limited space, we use internal ratchet gearing. The pawl is fixed inside the ratchet wheel, and the advantage of using internal ratchet gearing is that it can save a lot of space. In addition, considering that the dimension of the chair is not very large, it is good to choose internal ratchet gearing.
5.11.1 The design of ratchet gearing

5.11.1.1 The shape of the ratchet gearing

![Asymmetric trapezoid, Asymmetric triangle, Asymmetric round](image)

*Figure 5.24 Different shapes of the ratchet gearing*

Comparing with these types of---the asymmetric trapezoid has strong load capacity and it can work when the load is very large while the asymmetric triangle and asymmetric round can only be allowed when the load is not large enough.

Throughout the whole process of exercises, the trainer lean against the back of the chair all the time, so in this project, we decide to use the ratchet gearing, which the shape of it is asymmetric trapezoid.

5.11.1.2 The determination of module and number of teeth

Similar to the gear, most of the dimensions of the ratchet gear are based on the module. However the standard module of the ratchet gear depends on the addendum circle \(d_a\).

\[
m = \frac{d_a}{z}
\]

The number of teeth \(z\) depends on the using condition and movement requirement. To some common feed ratchet gearing, we can determine the number of teeth by the smallest rotation angle of the ratchet gear, then we can use formula to calculate the module.

5.11.1.3 The dimensions of the ratchet gearing

After we determine the module and the number of teeth, we calculate other dimensions of the ratchet gearing. The following table shows some main dimensions.
Table 5-4 Dimensions of the ratchet gearing

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Quantity</th>
<th>Formula</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>Module</td>
<td>1, 1.5, 2, 2.5, 3, 3.5, 4, 5, 6, 8, 10</td>
<td>4</td>
</tr>
<tr>
<td>Z</td>
<td>Number of teeth</td>
<td>$Z = 2\pi / \theta_{\text{min}}$</td>
<td>20</td>
</tr>
<tr>
<td>$d_a$</td>
<td>Tip diameter</td>
<td>$d_a = m \cdot z$</td>
<td>80</td>
</tr>
<tr>
<td>p</td>
<td>Circular pitch</td>
<td>$p = \pi \cdot m$</td>
<td>12.57</td>
</tr>
<tr>
<td>h</td>
<td>Tooth height</td>
<td>$h = 0.75m$</td>
<td>3</td>
</tr>
<tr>
<td>a</td>
<td></td>
<td>$a = m$</td>
<td>4</td>
</tr>
<tr>
<td>$a_1$</td>
<td>Working length of the pawl</td>
<td>$a_1 = (0.5 \sim 0.7)a = 0.6a$</td>
<td>2.4</td>
</tr>
<tr>
<td>$\alpha$</td>
<td></td>
<td>$\alpha = 20^\circ$</td>
<td>20°</td>
</tr>
<tr>
<td>b</td>
<td>Width of the ratchet</td>
<td>$b = (1 \sim 4)m = 4m$</td>
<td>16</td>
</tr>
<tr>
<td>$h_1$</td>
<td>Tooth slant</td>
<td>$h_1 = h / \cos \alpha$</td>
<td>3.2</td>
</tr>
<tr>
<td>$r_f$</td>
<td>Ratchet dedendum circle radius</td>
<td></td>
<td>1.5</td>
</tr>
</tbody>
</table>
5.12 Material choice

The choice of material of the multi-functional fitness chair is one of the most important part in the whole design. The mechanical properties of the material determine the stability and the security of the product. In addition, the properties will also effect the results of the hand calculations and the simulation. Comparing to the normal chair, the multi-functional fitness chair focus more on the stability. So in this part, we are going to choose the material under three requirements. Aluminum 6061 is the final material which is chosen for the main material of the multi-functional fitness chair.

1. The intensity of the material

This is the first factor need to be considered. As mentioned before, the intensity of the material determines whether the chair is safe or not. The following table shows the mechanical properties of Aluminum 6061-T4.

<table>
<thead>
<tr>
<th>Mechanical Properties</th>
<th>Metric</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness, Brinell</td>
<td>65</td>
<td>AA; Typical; 500 g load; 10 mm bal</td>
</tr>
<tr>
<td>Property</td>
<td>Value</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Hardness, Knoop</td>
<td>88</td>
<td>Converted from Brinell Hardness Value</td>
</tr>
<tr>
<td>Hardness, Vickers</td>
<td>75</td>
<td>Converted from Brinell Hardness Value</td>
</tr>
<tr>
<td>Ultimate Tensile Strength</td>
<td>241 MPa</td>
<td>AA; Typical</td>
</tr>
<tr>
<td>Tensile Yield Strength</td>
<td>145 MPa</td>
<td>AA; Typical</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>22%</td>
<td>AA; Typical; 1/16 in. (1.6 mm) Thickness</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>25%</td>
<td>AA; Typical; 1/2 in. (12.7 mm) Diameter</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>68.9 GPa</td>
<td>AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.</td>
</tr>
<tr>
<td>Poisson's Ratio</td>
<td>0.33</td>
<td>Estimated from trends in similar Al alloys.</td>
</tr>
<tr>
<td>Fatigue Strength</td>
<td>96.5 MPa</td>
<td>AA; 500,000,000 cycles completely reversed stress; RR Moore machine/specimen</td>
</tr>
<tr>
<td>Machinability</td>
<td>50%</td>
<td>0-100 Scale of Aluminum Alloys</td>
</tr>
<tr>
<td>Shear Modulus</td>
<td>26 GPa</td>
<td>Estimated from similar Al alloys</td>
</tr>
<tr>
<td>Shear Strength</td>
<td>165 MPa</td>
<td>AA; Typical</td>
</tr>
</tbody>
</table>

Through the research, the Aluminum 6061-T4 has an ultimate tensile strength of 241 MPa and yield strength of at least 110 MPa. After the simulation, combining with these main datum, we can make sure that the product we designed is safe enough.

2. The weight of the material
Although the chair has two crossbeams at the bottom, and four anti-skid pads at the both sides of the crossbeams., the function of the anti-skid pads is to reduce the damage to the floor, in the other word, reduce the force from the product to the floor, if the total weight of the chair is too big, it will also hurt the floor, it means, using light material can effectively avoid this situation happens.

3. The price of the material

Under normal circumstances the price of the material and the intensity of the material are the two opposite factors. The material with high intensity, means it have a higher requirement for casting, and it is obvious that the price will higher than the normal one. Therefore, what should we do is to find a balance between these two main factors.
6 Instruction

6.1 Abstract

Nowadays, more and more people do not have enough time to do exercises, thus, the lack of exercise cause a series of health problems. This multi-functional fitness chair is designed for the people who wants to have light weight training to keep fit at home and for some fitness training beginners. The product has different forms, this instruction will show people how to transform the product into different forms and which is the working muscles in different exercises.

6.2 Product overview

This product combines with a variety of fitness equipment, so it enables people to do different kinds of exercises at home. Through different exercises, different parts of muscles can be exercised. Some details about which muscles can exercised through exercises will be introduced in the next part.
The trainer can have lat pull, rowing exercise, leg extension, sit-up exercise and some other exercises.

6.3 Main exercises

6.3.1 Lat pull

1. Adjust the seat of the chair, by using the locking screw 1. After the seat moving into a comfort position, then screw up the locking screw to fix the seat.

2. During the whole process of lat pull, the back of the chair should be vertical all the time, otherwise, it will not only affect the training effect, but also do damage to your back.

3. The connecting rod 1 cannot be used in this exercise, so we just remove the connecting rod from the slider, and then fix the connecting rod 1 in the back of the chair by using a pin.

4. Using a ratchet and pawl to control the angle of the back, moving the back and makes it vertical. However, when the back moves over the vertical angle, just pull out the end cap of the ratchet and pawl. The end cap is connected with the pawl claw, after we pull out the end cap, the back can rotate freely.

5. The function of the leg fixing rod is to fix thighs, if the load is too large, a leg fixing rod can keep people from being pulled up. The leg fixing rod can also be adjusted by a pin. Make the leg fixing rod in a correct position.

6. Adjust the telescopic rod by using locking screw 2 in a comfortable position which can reach the handle.

7. Using the back springs. According to your ability to adjust the type and quantity of spring.
6.3.2 Rowing exercise

1. Different from the lat pull, the seat of the chair should move on the dual-shaft linear rail smoothly, we need to loosen the locking screw 1.

2. During the rowing exercise, we also need not use connecting rod 1, fixing it in the back of chair like the process be introduced in the lat pull part.

3. Using a ratchet and pawl to fix the back at any angle. The requirements of the angle is not high, so just adjust the back as you like.

4. Loosen the locking screw 3 to put the telescopic rod on the level. When the telescopic rod lays on the leg support, screw up the locking screw 3 to fix the rod.

5. We also can use locking screw 2 to adjust the length of the telescopic rod.
6. Because the leg fixing rod will prevent the kneel in the rowing exercise, so we need to loosen the pin which fix the leg fixing rod and lay it on the telescopic rod.

7. Putting your legs on the pedal.

8. Using the back springs. According to your ability to adjust the type and quantity of spring.

6.3.3 Leg extension

1. Adjust the seat of the chair by using the locking screw 1. After the seat moving into a comfort position, then screw up the locking screw to fix the seat.

2. In the leg extension, it is similar to the lat pull, the back of the chair should also be vertical all the time. Fixing the connecting rob 1 and adjusting the ratchet and pawl.

3. It does not matter that whether using leg fixing rob to fix the thighs or not. If you do not want to use leg fixing rob, changing the position it by using pin.

4. Using the back springs. According to your ability to adjust the type and quantity of spring.

Figure 6.3 Rowing exercise
5. Putting the feet under the sponge.
6. Holding the handle of the chair.

6.3.4 Sit-up exercise

In order to make our product more widely applicable to different groups of people, there are two different forms to have sit-up exercise. One is doing sit-up exercise without weights, like the normal sit-up machine, the angle of the back can be adjusted as you like. The other one is doing sit-up exercise with weights, this form of sit-up exercise is suitable for the people who want to have further exercise.

6.3.4.1 Without weights

1. Adjust the seat of the chair by using the locking screw 1, at the position that the feet can reach the pedal, then screw up the locking screw to fix the seat.
2. Although in this sit-up exercise, there is no need to use springs here, the connecting rod 1 also need to be fixed in the back of the chair, in order to increase the stability of the product.

3. Using ratchet and pawl to control the angle. The bigger the angle, the more obvious the effect of exercise.

4. Putting the feet into the pedal to fix it.

Figure 6.5 Sit-up without weights

6.3.4.2 With weights

Different from the sit-up without weights, the force provided by the spring act as weights in this exercise. This form of exercise is more suitable for the people who want to have further exercise.

1. In this form of sit-up exercise, people need to turn their face to the back. Using arms to grip the sponge 1, through the abdominal muscles to push the back forward, in this case, the abdominal muscles can be exercised.

2. Adjusting the angle of the sponge 1, ensure that the sponge is in front of the chest, then lock it by using the pin at the back of the chair.

3. Pull out the end cap of the ratchet and pawl, enables the back of the chair can rotate freely.
4. The function of the connecting rod 1 is connecting the back of the chair and the slider. At the other side of the slider is connecting rod 2, through the slider, the spring can provide forces to prevent the movement of the back.

5. Since the trainer is facing to the back, the feet can be fixed by the sponge 2.

6. Using the front springs. According to your ability to adjust the type and quantity of spring.

![Figure 6.6 Sit-up with weights](image)

6.4 Extra exercises

Using the same equipment but with different posture can exercise different parts of muscles. Similarly, this product can also provide some extra exercises, like the Musculus Biceps Brachii Curl and the Cable Pushdown to exercise arm muscles. Besides the long handle we introduce in the figure, we also provide other types of handle for different exercises, like the short handle, V-bar and rope attachment.
Figure 6.7 Musculus biceps brachii curl [24]

Figure 6.8 Cable Pushdown [25]
6.4.1 Musculus Biceps Brachii Curl

1. Raising the sponge 3, keeping it vertical and taking off the hook.
2. Hang up the hook to the short handle or the rope attachment, at the other side of the rope which is connected with the connecting rod 2.
3. Fixing the connecting rod 1 in the back of chair, otherwise the back will rotate through the slider while doing exercise.
4. Using the back springs. According to your ability to adjust the type and quantity of spring.

![Figure 6.9 Musculus biceps brachii curl](image)

6.4.2 Cable Pushdown

This exercise is similar to the lat pull, the difference between them is the posture of the trainer. Doing Cable Pushdown need the trainer stand in front of the telescopic rod. However, the lat pull need the trainer at a sitting posture.
Through the Cable Pushdown, Triceps Brachii Lateral Head, Triceps Brachii Long Head and Triceps Brachii Medial Head will be exercised [26].

6.5 Weights

Considering that in different exercises, different weights are needed. So it means the weights should be optional. For the product, there two different kinds of springs can be chosen, which each of the spring can provide 100 N and 150 N weights. Because of the stability, the number of springs that are used must be even. There are 200 N, 300 N, 400 N, and 600 N four different weights can be chosen, which is more suitable for different users.
7 Chapter: Hand calculation

7.1 Welding

Joints subjected to bending

According to solid mechanics both normal stresses and shear stresses will rise at bending. These can be calculated from:

\[
\sigma_b = \frac{M_b}{I_x} \cdot y \quad (1)
\]

\[
\tau_b = \frac{T}{I_x} \cdot S 
\]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I_x)</td>
<td>Moment of inertia about the neutral axis. The calculation is done simply to consider the a-dimension is tilted in the girdle plane, figure 20 II</td>
</tr>
<tr>
<td>(y)</td>
<td>The distance from neutral axis to the plane where the stress should calculated.</td>
</tr>
<tr>
<td>(T)</td>
<td>Shear force</td>
</tr>
<tr>
<td>(S)</td>
<td>Static torque for the part of the cross-sectional area that is outside the reference plane.</td>
</tr>
<tr>
<td>(b)</td>
<td>Cross-sectional width of calculation plane.</td>
</tr>
</tbody>
</table>

For the ring-shaped cross-sections that weld in figure 1 forms get from equations (1) and (2) a stress distribution in the height according Figure 1 a. As follows of this is that \(\sigma_b\) become maximal at the extreme fibers and \(\tau_b\) become maximum in neutral plane. Where one stress has its maximum is thus while the second is 0.

Apart from very short beams (L in figure 1 c very small) we can usually ignore and let be the design criterion. For the ring-shaped cross-section, such as weld in figure 20. However, we must also check section B (see fig. 1 b),
because here both and will be occur with relatively large amount.

Looking at a cross-section of the upper weld, fig 1 I, we find that the stress in the weld must be divided into component forces and in order to fulfill with fig 11.

Figure 7.1 Structure of welding

\[
\begin{align*}
\sigma_b &= \frac{\sigma_1}{\sqrt{2}} + \frac{\tau_1}{\sqrt{2}} \\
\sigma_1 &= \frac{\tau_1}{2} \\
\sigma_b &= \frac{2 \sigma_1}{\sqrt{2}} \\
\sigma_1 &= \frac{\tau_1}{2} = \sigma_b \\
\sigma_1 &= \tau_1 = \sigma_b \\
\sigma_j &= \sqrt{\sigma_1^2 + 3\tau_1^2} = \sigma_b * 2 = 1.1\sigma_{tilt}
\end{align*}
\]

For the welds in figure 1 is designated as the strength table

\[
I_x = \frac{1}{12} (BH^3 - bh^3) = \frac{1}{12} [(b + 2a)(h + 2a)^3 - bh^3]
\]

And in section (fig. 1 b) becomes \( y = \frac{h}{2} + a \)

When the attachment is \( M_b = F * L \)
In the section B calculated $\sigma_b$ in the same way as in section A, but with $y = \frac{h}{2}$

As shown in figure 1 a is almost same for the entire height $h$ and relatively small at the top and bottom welds. Thus one makes the simplification that assumes that all the shear force $T$ only transfer of life welds (i.e. those with height $h$) and is evenly distributed over the length. Therefore $\tau_b = \frac{T}{h+2a}$

This stress will be parallel with $T$, i.e., it will correspond in fig 1 c.

The stress in section B is now obtained from equation 4

$$\sigma_j = \sqrt{\sigma_1^2 + 3\tau_1^2 + 3\tau_2^2}$$

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h$</td>
<td>40</td>
<td>mm</td>
</tr>
<tr>
<td>$b$</td>
<td>70</td>
<td>mm</td>
</tr>
<tr>
<td>$h'$</td>
<td>35</td>
<td>mm</td>
</tr>
<tr>
<td>$b'$</td>
<td>65</td>
<td>mm</td>
</tr>
<tr>
<td>$a$</td>
<td>5</td>
<td>mm</td>
</tr>
<tr>
<td>$F$</td>
<td>686</td>
<td>N</td>
</tr>
<tr>
<td>$L$</td>
<td>400</td>
<td>mm</td>
</tr>
</tbody>
</table>
Solution:

\[ a = 5\text{mm} \]

Safety value for beam bar

\[ M_b = F \times L = 686 \times 400 \times 10^{-3} = 274.4 \text{ N} \cdot \text{m} \]

Beam:

\[ \sigma_{b \ max} = \frac{M_b}{I_x} \cdot \frac{h}{2} = \frac{274.4 \times 40 \times 10^{-3}}{12 \left(70 \times 40^3 - 64 \times 34^3\right) \times 10^{-12}} \]

\[ = 67.045 \text{ Mpa} \]

Weld

\[ I_x = \frac{1}{12} (BH^3 - bh^3) = \frac{1}{12} \left[(b + 2a)(h + 2a)^3 - bh^3\right] = 4.6 \times 10^{-7} \]

Section A

\[ \sigma_{b \ max} = \frac{M_b}{I_x} \cdot \left(\frac{h}{2} + a\right) = 14.913 \text{ Mpa} \]

\[ \sigma_\perp = \frac{\sigma_\perp}{\sqrt{2}} + \frac{\tau_\perp}{\sqrt{2}} = 2 \frac{\sigma_\perp}{\sqrt{2}} \]

\[ \sigma_{\max} = \tau_{\max} = \frac{\sqrt{2}}{2} \sigma_b \]

\[ \sigma_j = \sqrt{\sigma_\perp^2 + 3 \tau_\perp^2} = \sigma_b \times 2 = \sqrt{2} \sigma_b = \sqrt{2} \times 14.913 = 21.090 \text{ Mpa} \]

Section B

\[ \sigma_{b \ max} = \frac{M_b}{I_x} \cdot \frac{h}{2} = 11.930 \text{ Mpa} \]

\[ \sigma_\perp = \frac{\sigma_\perp}{\sqrt{2}} = \frac{11.930}{\sqrt{2}} = 8.436 \text{ Mpa} \]

\[ \tau_\parallel = \frac{F}{h \times 2a} = \frac{686}{40 \times 2 \times 5 \times 10^{-6}} = 1.715 \text{ Mpa} \]

\[ \sigma_{\parallel}^b = \sqrt{\sigma_\perp^2 + 3 \tau_\perp^2 + 3 \tau_\parallel^2} = 17.024 \text{ Mpa} \]
# 7.2 Gear calculation

### Table 7-1 Known datum of gears

<table>
<thead>
<tr>
<th>Known</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input power</td>
<td>0.2</td>
<td>KW</td>
</tr>
<tr>
<td>Pinion speed</td>
<td>180</td>
<td>r/min</td>
</tr>
<tr>
<td>Gear ratio</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Working life</td>
<td>Provided work 300 days a year, two hours per day</td>
<td></td>
</tr>
</tbody>
</table>

### Solution:

1. Choice of gear, accuracy, material, number of teeth

   1) According to fig’ Transmission Scheme. Spur gear is the best choice.

   2) As general working machine, low speed is needed, so 7 Accuracy (GB10095-88) is more suitable.

   3) Material choice, according to table 10-1, the material of Pinion is quenched and tempered steel No.45, hardness is 250HB; the material of Wheel is normalizing steel No.45, hardness is 210HB.

   4) Number of teeth

   Pinion: \( z_1 = 24 \)

   Wheel: \( z_2 = 48 \)

2. Design the tooth contact strength

   According to design calculate formula (10-9a)
\[ d_{1t} = 2.32 \frac{3 \sqrt{KT_1 \cdot \frac{u + 1}{u} \left( \frac{Z_k}{\sigma_H} \right)^2}}{\phi_d} \]

(1) Determine every numerical in the formula

1) Load factor \( K_t = 1.3 \)

2) Calculate the Torque of the pinion

\[ T_1 = \frac{95.5 \times 10^5 P_1}{n_1} = \frac{95.5 \times 10^5 \times 0.2}{180} = 1.06 \times 10^4 N \cdot mm \]

3) According to the table 10-7 we choose the Tooth width coefficient \( \phi_d = 1.0 \)

4) According to the table 10-6, we find the Material influence coefficient \( Z_k = 189.8 \, \text{Mpa}^\frac{1}{2} \)

5) According to the tooth surface hardness fig 10-21d [2], 10-21c [2], Contact fatigue strength limit of the pinion \( \sigma_{Him1} = 600 \, \text{Mpa} \); Contact fatigue strength limit of the wheel is \( \sigma_{Him2} = 560 \, \text{Mpa} \).

6) Calculate the Stress cycles based on the formula 10-13

\[ N_1 = 60n_1jL_h = 60 \times 180 \times 1 \times 600 \times 5 = 3.24 \times 10^7 \]

\[ N_2 = \frac{3.24 \times 10^7}{2} = 1.62 \times 10^7 \]

7) According to the fig 10-19 we choose the Contact fatigue life factor

\[ K_{H1} = 0.90 \]

\[ K_{H2} = 0.95 \]

8) Calculate the contact fatigue allowable stress

Choose the Failure Probability 1%, safety factor \( S = 1 \), according to the formula 10-12

\[ [\sigma_H]_1 = \frac{K_{H1} \sigma_{Him1}}{S} = \frac{0.9 \times 600}{1} = 540 \, \text{Mpa} \]

\[ [\sigma_H]_2 = \frac{K_{H2} \sigma_{Him2}}{S} = \frac{0.95 \times 560}{1} = 532 \, \text{Mpa} \]

(2) Calculate

1) Calculate the pinion’s reference diameter \( d_1 \), into a smaller value of \([\sigma_H]\)
\[ d_{1t} = 2.32 \frac{3}{d} \sqrt{\frac{K_T \cdot \frac{\mu + 1}{\mu} \left( \frac{Z_E}{\sigma_H} \right)^2}{d^2}} = 32 \text{ mm} \]

2) Calculate the Circumferential speed \( v_0 \)

\[ v_0 = \frac{\pi d_{1t} n_1}{60 \times 1000} = \frac{\pi \times 32 \times 180}{60 \times 1000} = 0.302 \text{ m/s} \]

3) Calculate the Face width

\[ b = \phi_d \cdot d_{1t} = 32 \text{ mm} \]

4) Calculate the ratio of face tooth width and tooth height \( \frac{b}{h} \)

Module \( m_t = \frac{d_{1t}}{z_1} = \frac{32}{24} = 1.33 \text{ mm} \)

Tooth depth \( h = 2.25 m_t = 2.25 \times 1.33 = 3 \text{ mm} \)

\[ \frac{b}{h} = \frac{32}{3} = 10.67 \]

5) Calculate the load coefficient

Choose the dynamic load factor as \( K_v = 1.12 \) based on \( v_0 = 0.302 \text{ m/s} \)

Spur gear, \( K_{Ha} = K_{Fa} = 1 \)

Find the Using coefficient \( K_A = 1.25 \) in table 10-2

Get \( K_{H\beta} = 1.40 \) based on \( \text{asymmetrically support} \)

7 Accuracy

According to \( \frac{b}{h} = 10.67, K_{H\beta} = 1.40 \) find the \( K_{F\beta} = 1.31 \) in fig 10-13; so the load coefficient:

\[ K = K_A K_v K_{Ha} K_{H\beta} = 1.25 \times 1.02 \times 1 \times 1.40 = 1.785 \]

6) According to the actual load factor to correct the calculated pitch diameter

\[ d_1 = d_{1t} \sqrt[3]{\frac{K}{K_t}} = 32 \times \sqrt[3]{\frac{1.785}{1.3}} = 35.567 \text{ mm} \]

7) Calculate the module
2. Check by root bending strength

According to design calculate formula (10-4)

\[ \sigma_F = \sigma_{F0}Y_{Sa} = \frac{KF_tY_{Fa}Y_{Sa}}{bm} \leq [\sigma_F] \]

(1) Determine every numerical in the formula

1) Load coefficient \( K = 1.785 \)

2) \( F_t = \frac{2T_1}{d_1} = \frac{2 \times 1.06 \times 10^4}{35.567} = 596.06 N \)

3) Get \( Y_{Fa1} = 2.65, Y_{Fa2} = 2.55 \) and \( Y_{Sa1} = 1.58, Y_{Sa2} = 1.61 \) by fig 10-5

4) Face width \( b = \phi_d \cdot d_{1t} = 32 mm \)

5) Module \( m = 2 \)

6) Calculate root bending strength

\[ \sigma_{F1} = \frac{KF_tY_{Fa1}Y_{Sa1}}{bm} = \frac{1.785 \times 596.06 \times 2.65 \times 1.58}{32 \times 2} = 69.61 Mpa \]

\[ \sigma_{F2} = \frac{KF_tY_{Fa2}Y_{Sa2}}{bm} = \frac{1.785 \times 596.06 \times 2.55 \times 1.61}{32 \times 2} = 68.25 Mpa \]

7) According to the fig 10-18\(^2\), get the bending fatigue life factor \( K_{FN1} = 0.93, K_{FN2} = 0.97 \)

8) According to the fig 10-20(b), 10-20(c), get bending fatigue limit

\( \sigma_{FE1} = 580 Mpa \) and \( S_F = 1.4 \)

\( \sigma_{FE2} = 450 Mpa \) and \( S_F = 1.4 \)

9) Root bending fatigue allowable stress
3. Calculate gear geometry

(1) Reference diameter

Pinion: \( d_1 = mZ_1 = 2 \times 24 = 48 \text{ mm} \)

Wheel: \( d_2 = mZ_2 = 2 \times 48 = 96 \text{ mm} \)

(2) Face width

\[ b = \phi_d \cdot d_{1t} = 32 \text{ mm} \]

(3) Addendum Coefficient

\[ h_a^* = 1 \]

(4) Addendum

\[ h_a = h_a^* \cdot m = 1 \times 2 = 2 \text{ mm} \]

(5) Headspace coefficient

\[ C^* = 0.25 \]

(6) Dedendum

\[ h_f = (h_a^* + C^*)m = (1 + 0.25) \times 2 = 2.5 \text{ mm} \]

(7) Full-height tooth

\[ h = h_a + h_f = 2 + 2.5 = 4.5 \text{ mm} \]

(8) Tip diameter

Pinion: \( d_{a1} = d_1 + 2h_a = 48 + 4 = 52 \text{ mm} \)

Wheel: \( d_{a2} = d_2 + 2h_a = 96 + 4 = 100 \text{ mm} \)
(9) Root diameter

\[
\text{Pinion: } d_{f1} = d_1 - 2h_f = 48 - 5 = 43 \text{ mm} \\
\text{Wheel: } d_{f2} = d_2 - 2h_f = 96 - 5 = 91 \text{ mm}
\]

(10) Base diameter

\[
\text{Pinion: } d_{b1} = d_1 \cos \alpha = 48 \times \cos 20^\circ = 45.105 \text{ mm} \\
\text{Wheel: } d_{b2} = d_2 \cos \alpha = 96 \times \cos 20^\circ = 90.210 \text{ mm}
\]

(11) Pitch

\[
p = \pi m = 6.283
\]

Figure 7.2 Parameters of the gears [27]

7.3 Cylindrically helical tension spring design

1. Consider the spring will provide 100N and 150N when the spring completely tensioned, and the deflection at ultimate load required to be about 250mm.

2. So choose the low manganese spring steel 65Mn as the spring material.
Figure 7.3 Mechanical properties of 65Mn [28]

3. Spring index:

Choose $C = 5\sim8$ generally

Consider the spring deflection need to be maintain the requirement under the given forces.

$C = 8$

Estimates take diameter of wire $d = 2.5\ mm$

According to the Table 16-3, get the wire’s allowable stress $\sigma_B = 1650\ MPa$.

4. Calculate the diameter of wire

$F = 150\ N$

$$d' \geq 1.6 \sqrt{\frac{F_{max}KC}{\tau}} = 1.6 \times \sqrt{\frac{150 \times 1.184 \times 8}{0.4 \times 1650}} = 2.348\ mm$$

Choose the next standard value $d' = 2.5\ mm$

$F = 100\ N$

$$d' \geq 1.6 \sqrt{\frac{F_{max}KC}{\tau}} = 1.6 \times \sqrt{\frac{100 \times 1.184 \times 8}{0.4 \times 1600}} = 1.946\ mm$$

Choose the next standard value $d' = 2.0\ mm$

5. Calculate the deflection at ultimate load

$F = 150\ N$
6. Checking Fatigue strength

When the load changed from 0 to maximum, calculate the minimum and maximum cyclic shear stress generated by spring internal material.

\[
\tau_{max} = \frac{8KD}{\pi d^3} \cdot F_{max} = \frac{8 \times 1.184 \times 12}{\pi \times 2.0^3} \cdot 100 = 452.25 \text{ MPa}
\]

\[
\tau_{max} = \frac{8KD}{\pi d^3} \cdot F_{max} = \frac{8 \times 1.184 \times 20}{\pi \times 2.5^3} \cdot 150 = 578.89 \text{ MPa}
\]

\[
\tau_{min} = \frac{8KD}{\pi d^3} \cdot F_{min} = 0
\]

Fatigue strength safety factor:

\[
S_{ca} = \frac{\tau_0 + 0.75 \tau_{min}}{\tau_{max}} \geq S_F
\]

Where

\(\tau_0\) - Pulsating cyclic shear fatigue limit of the spring material

\(S_F\) - Design safety factor of fatigue strength of the spring

\(S_F = 1.3 \sim 1.7\)

\(F = 150 \text{ N}\)

\[
S_{ca} = \frac{0.45 \times 1650 + 0}{578.89} = 1.32 \geq S_F
\]

\(F = 100 \text{ N}\)

\[
S_{ca} = \frac{0.45 \times 1700 + 0}{452.25} = 1.69 \geq S_F
\]

7. Checking static stress intensity

Static strength safety factor:

\[
S_{Sca} = \frac{\tau_a}{\tau_{max}} \geq S_S
\]
7.4 The choice of spring

The springs for the gym equipment are different from the normal springs. So the spring should be manufactured according to the parameter by hand calculation. For our product, two springs are needed, which different in parameter.

*Table 7-2 Main parameter of different springs*

<table>
<thead>
<tr>
<th>Parameters</th>
<th>100 N</th>
<th>150 N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean diameter of coil</td>
<td>D</td>
<td>16 mm</td>
</tr>
<tr>
<td>Diameter of wire</td>
<td>d</td>
<td>2 mm</td>
</tr>
<tr>
<td>Spring index</td>
<td>C</td>
<td>8</td>
</tr>
<tr>
<td>Number of active coils</td>
<td>n</td>
<td>100</td>
</tr>
<tr>
<td>Length of the spring</td>
<td>(L_0)</td>
<td>200 mm</td>
</tr>
<tr>
<td>Types of ends</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full loop side</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 7.4 Types of the spring [29]*
Figure 7-4 shows the types of the spring which manufactured by a Chinese company, Dongguan TinFin Hardware Products Co. This company offers customers products with competitive price and good quality. That is why this company are chosen.

8 Chapter: FEM simulation

8.1 Welding simulation

Before having stress analysis, we need to use welding function in Inventor 2016 at first, as the previous welding hand calculation shows that the dimension is 5mm, then we use welding function to combine two bars together.

![Welding function in Inventor](image)

Figure 8.1 Welding function in Inventor

When having sit-up exercise, the trainer faces to the back of the chair, and almost the whole weight is exerted to the back of the chair. We assume that the force is 700N, which is perpendicular to the back.

After the welding simulation in Inventor, we found that the result by simulation 18.19 MPa is similar to the hand calculation 17.024 MPa. The following figure is the result by simulation.
8.2 Gear simulation

Then the FEM is simulated in Inventor. There is a 600 N force on the meshing part of two gears, the maximum Von Mises Stress simulate by FEM is 136.9 MPa, comparing with the result in hand calculation, \( [\sigma_{\text{p2}}] = 311.79 \text{ MPa} \) which is larger than the result by FEM, it means it is strong enough.

Besides, it can be seen in figure 8-3, the Von Mises Stress in the tooth root is 68.4 MPa, according to the result of root bending strength \( \sigma_{\text{p1}} = 69.61 \text{ MPa} \), the result by FEM is 68.4 MPa, which is similar to the root bending strength. It can be proved that both the result by hand calculation and the result by FEM are correct.
8.3 Spring simulation

Through the simulation by Inventor, the deflection at ultimate load for each type of spring is shown in the following table, comparing them with the result by hand calculation.

*Table 8-1 The deflection at ultimate load for different types of spring*

<table>
<thead>
<tr>
<th></th>
<th>100 N</th>
<th>150 N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand calculation</td>
<td>259.24 mm</td>
<td>248.87 mm</td>
</tr>
<tr>
<td>FEM</td>
<td>260.6 mm</td>
<td>248.6 mm</td>
</tr>
</tbody>
</table>
From the table 8.1, there is no difference between the results by hand calculation and the results by FEM. So it can be said that both of the results are correct.
9 Chapter: Conclusion and future work

In order to make the final product more likely to be manufactured, more details of the product are focused on. From every screw to every part of the product are designed following the measurement result. Like the distance between the chair to the pedal, the length of the legs from different people are measured.

Neither of group members is professional fitness, so an investigation is necessary. Before the design, a large number of fitness equipment in the gym in Karlskrona are investigated, not only the operation of the fitness equipment, but also the functions of them. Besides, combining the information on the internet and the interview from professional fitness, some training sites and the working muscles have been known.

However, the product also have some disadvantages. As a mechanical, fitness equipment, the security is the most important factor, it means every parts of the product need to be tested, both the security and the stability. Due to the limitation of the time, only some main parts are tested in this report, if the product need to be manufactured, a further test is essential.

There is no doubt that a mechanical structure is more safety than a structure with electric technique. However using electric technique can make the product have a higher functionality. In order to further our product, an electric technique will be added, connecting a deformation sensor with the spring, through a series of data collection, data integration and data conversion. Finally get a quantity about the burning calories, and reflect on a monitor to show the user which is a good way to know the training effect.
Reference


Appendix 1:

Drawing of the full equipment assembly
Appendix 2:

Drawing of main components