Saimaa University of Applied Sciences
Lappeenranta
Mechanical Engineering and Production Technology

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Parking Shaft

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Abstract
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The purpose of the project was to design a shaft that can park two cars in the
garage for the families.

The information was gathered from the Internet, lecture materials, and
measuring the family garage in China. It was difficult to design the structure of
the shaft, actually we design three different structures for the shaft were
designed, and was chosen the one that can let the door of the garage open or
close as normally.

The final result of this thesis was to help the families to park two cars in the
old garage, which could only park one car before. The families can get more
space to use for other things.

Keywords
Mechanical parking system, Parking, Hydraulic, Garage, 2-floors shaft
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1 Introduction

1.1 Background

With the booming of the Chinese economy, the living standard has remarkable improvement. The explosion in the number of cars is a phenomenon. As of late 2003, the number of vehicles in China is 12 427 672. The number of private cars is 4 890 387, the rise is 1 462 441 from 2003 to 2003, the rate is 42.7%.

Parking spaces cannot synchronize the growth of the number of vehicles at the same time. As in many new households, the district and the parking ratio is 1:1. Vehicles parked nowhere is the problem of the urban social, economic and transport development to a certain extent.

Mechanical parking equipment is also called stereo garage. Compared with traditional garage, the most obvious advantage is that the space can be maximum utilization; it is safer and more convenient. This kind of equipment is useful solve no parking space in the limit space of city.

Chinese government has made policies clear to support stereo garage like an important technical. (Promulgated by Decree No. 6 of the People's Republic of China on Jan 1, 1998). Overall, we can see the stereo garage is wide market and vast economic and social efficiency.

1.2 Purpose

From a research for private cars we can see that the number of private cars is increasing every year. For example, the number of cars in Chengdu was 1
600 000 in 2005, and it is increased by the rate of 80 000 per year. Data shows that currently in Chengdu, \( \frac{2}{3} \) of the vehicles have no parking place. The purpose is to design parking equipment for a private garage.

Nowadays, the private garage normally can park only one car, but most of the families have more than one car. So the task was to design mechanical equipment that can store 2 cars in one normal garage. It is called a parking shaft.

The idea is that the cars can go out or get in at any time without any problems. When we want to move any one of the cars, we do not need to move the other one.

Figure 1
This picture shows the different structure of the garage in China.
2 The overview of mechanical parking garage

Garage equipment develops especially in Japan has been going on nearly 30-40 years, whether technically or in terms of experience it has been a success. In the beginning of the 1990s also China developed mechanical parking equipment.

2.1 Classifying the MPS

Chinese JB/T 8713 - 1998\(^1\) (Mechanical parking systems : classification, models and basic parameters), classifies the mechanical parking systems.

- Lifting and transferring
  The code is SX
  It means using the parking board up-down or (and) lateral translation to parking cars.

![Diagram of mechanical parking systems]

Figure 2

---

\(^1\)<Mechanical parking systems : classification, models and basic parameters>http://www.docin.com/p-23343789.html
- Vertical continuous
  The code is CX
  It means the transport apparatus moves vertically to park cars.

![Figure 3](image)

- Horizontal continuous
  The code is SX
  It means the transport apparatus moves horizontally to park cars.

![Figure 4](image)
• Multi-storey cycle
  The code is DX
  The transport apparatus makes the parking units to do circulation movement.

![Figure 5]

• Horizontal movement
  The code is PY
  Parking boards in the same floor do the horizontal movement.

![Figure 6]
• Roadway Stacker
  The code is XD
  Aisle stacking crane moves the car which is in the transport apparatus to the parking unit.

Figure 7

• Vertical up-down
  The code is CS
  Use lifter to the floor, then use storage/retrieve machine.
- Simplicity up-down

The code is JS

Use lift and tilt mechanisms to park cars.
3 Choosing the mode by comparing the MPS

From the introduction of mechanical parking systems, we can see the advantages of each MPS.

3.1 Lifting and transferring

Figure 10(1)
In lifting and transferring garage modular design, each module can be designed into two, three, four levels, the five-story, semi-submerged in various forms, such as the number of parking spaces from a few to hundreds. This applies three-dimensional garage on the ground and underground car parks, configuration flexibility and low cost.

- **Features of product**
  a) Saves space, the configuration flexibility, shorter construction period.
  b) Low prices, firefighting and exterior decoration with a total investment on small foundations.
  c) Uses automatic control, simple structure, safe and reliable.

Figure 10(2)
http://imgchina.tradeprince.com/723/20100312/92ad98e2-bebe-455a-be3f-507502d287d7.jpg
d) Access to quick, short waiting times.

e) Running a smooth, low noise.

f) Applies to commercial, offices, and residential quarters supporting the use of car parks.

- Cost about 400 000 € (4 floors like figure 10)$^2$

3.2 Roadway Stacker

Figure 11

http://cn.sm160.com/Img/Product/00/00/32/70/327014.jpg

$^2$http://www.projectbidding.cn/zaobiao/gonggao/20091010/2002540883.html
Aisle stacking garage is used as a stacking machine tool to access vehicles, so the stacker requires high technology, single stacker need higher costs, so aisle stacking applied to the parking garage needs more customers. This garage has very high degree of automation, totally enclosed construction, and it is very safe.

- Cost about 700,000-1,000,000 €³

### 3.3 Vertical up-down

![Figure 12](http://www.szsdxf.com/upload/08_01.jpg)

³http://www.sm160.com/Buyer/OfferDetail/000-0730-424.html
Vertical up-down garage is similar to the elevator. Both sides of the elevator have parking units. The ground normally needs a vehicle rotary table, so the car does not need to be turned round by the driver. This kind of garage always needs very high height (dozens of meters), high requirement of equipment, so the cost is very high, but it takes the smallest area.

- Cost: more than 1,000,000 €

---

4http://www.daynews.com.cn/sxjjrb/151543.html
3.4 Vertical Continue

![Vertical Parking System](http://www.user0.jqw.com/2010/11/10/311422/product/b20101111707514942.jpg)

Figure 13

http://www.user0.jqw.com/2010/11/10/311422/product/b20101111707514942.jpg

- Features of product:
  a) Small area, 6-10 vehicles can park in 2 parking units.
  b) Low cost.
  c) Short period to build.
d) Uses automatic control, safe and reliable operation.

- Cost about 500,000 €

3.5 Simplicity up-down

This is the simplest garage, very easy to build, and the cost of it is the cheapest. In this case, a parking unit always can park 1 or 3 cars. It is suitable for a private garage.

- Cost about 5 000 €

5http://detail.cn.china.cn/provide/detail,1309082710.html
From this contradistinction, the simplicity up-down garage is chosen for the project. A parking shaft move is designed by storage/retrieve machine.
4 Structure design for parking shaft

4.1 Basic dimensions

Garage
Width (side-to-side dimension) 3.5 m
Length 6 m
Height 4 m

Vehicle

<table>
<thead>
<tr>
<th>KINDS</th>
<th>Structure (m)</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minivan</td>
<td></td>
<td>3.50</td>
<td>1.60</td>
<td>1.80</td>
</tr>
<tr>
<td>Passenger car</td>
<td></td>
<td>4.80</td>
<td>1.80</td>
<td>2.00</td>
</tr>
<tr>
<td>Light bus</td>
<td></td>
<td>7.00</td>
<td>2.10</td>
<td>2.60</td>
</tr>
<tr>
<td>Medium bus</td>
<td></td>
<td>9.00</td>
<td>2.50</td>
<td>3.20(4.00)</td>
</tr>
<tr>
<td>Large bus</td>
<td></td>
<td>12.00</td>
<td>2.50</td>
<td>3.20</td>
</tr>
<tr>
<td>Articulated bus</td>
<td></td>
<td>18.00</td>
<td>2.50</td>
<td>3.20</td>
</tr>
<tr>
<td>Heavy truck</td>
<td></td>
<td>10.00</td>
<td>2.50</td>
<td>4.00</td>
</tr>
<tr>
<td>Articulated truck</td>
<td></td>
<td>16.50</td>
<td>2.50</td>
<td>4.00</td>
</tr>
</tbody>
</table>

Figure 15
Benz C 200 SW

http://www.hardingsteel.com/downloads.shtml

[Parking Lifts by Harding steel]

92" = 3.1 m
98" = 3.3 m
103" = 3.4 m
176" = 5.9 m
57" = 1.9 m
68" = 2.3 m
4.2 Choosing the type of the structure

At first, 3 different structures for the parking shaft are made.

Case 1:

In this structure, the whole steel board will move by $30^\circ$, it will make some danger for the car which is parked on the first floor.

Case 2:
In this structure the length of the moving steel board will be too long, it will make danger for the people and cars which are outside the garage and the door cannot close.

Case 3:

![Figure 19](image)

In this structure the move steel board is divided into 2 parts. So we can make sure the shaft will not make any danger for the cars and people inside or outside the garage.

4.3 Composes

Based on the structure of the garage, the shaft is designed like this.
Accommodates the most popular SUVs and minivans.

The parking shaft consists of four upright posts, one platform and hydraulic lifting cylinders.

Four upright posts give four supporting points to the platform and makes the platform safer.

The platform is divided into 2 parts. Four hydraulic lifting cylinders are used to rise and drop the steel platform, 2 for the upper one and 2 for the lower one. It has a self-standing, self-supporting unit. The cylinders have a common hydraulic power pack.
Figure 21

From the vehicle table, the first data for minivans is chosen.

- Length = 3.5 m
- Wide = 1.6 m
- Height = 1.8 m

To prevent the vehicle touching the upright posts, the distance between the vehicle and the upright post should be 8 cm, 10 cm is chosen.

For the platform

Length = 5 m (movable = 2 m, fixed part = 3 m)
4.4 Working process

This parking shaft can store two cars. The platform is for minivans.
Whatever which car move in or out at first, there is no problem in the program. And there is also no problem to open or close the door of the garage.

The car parked in the first floor can go in or out without any problem, when the 2 movable platforms close, both are kept on a horizontal line.

When the car, which will park in the second floor, wants to move in or out, the whole movable platform will be raised up by the cylinders. They make 30 degrees with the ground as a slope at first, after the car moves in or out in the second floor, the movable platform will get back to the normal place.

When the cars have parked in the right place, the door can be closed normally.
5 Hydraulic work part design

5.1 Basic parameters

Hydraulic type (Boom Type)

The values for the design work

<table>
<thead>
<tr>
<th>Name</th>
<th>Work Type</th>
<th>External load</th>
<th>Lifting time</th>
<th>Min. Height</th>
<th>Max. Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>He Linyuan,</td>
<td>Boom Type</td>
<td>1700 [kg]</td>
<td>30 [s]</td>
<td>1 [m]</td>
<td>1 [m]</td>
</tr>
<tr>
<td>Chen Han</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 24

This picture shows the information of shaft in hydraulic files.

Figure 25(1)
The measurements of the lift elements

- Length of the cylinder \([b] = 150\text{mm}\)
- Maximum lifting angle \(= 30^\circ\)
- Maximum lifting height \([H_{\text{max.}}] = 1\ 000 \text{mm}\)
- Length of the beam \([L] = 2\ 000\text{mm}\)
- Minimum lifting height \([H_{\text{min.}}] \leq\)

Figure 25(2)
5.2 Finding the situation for cylinder

\[ \beta_3 = 30^\circ \]
\[ a = 450 \text{ mm} \]
\[ b = 150 \text{ mm}; 2b = 300 \text{ mm} \]

LAW OF COSINES
\[ c^2 = a^2 + b^2 - 2ab \cos \gamma \quad (1) \]

From this formula, we can get:

\[ \cos \gamma = \frac{a^2 + b^2 - c^2}{2ab} \]

\[ \cos 30^\circ = \frac{c^2 + 450^2 - 300^2}{2 \times 450 \times c} \]

\[ \rightarrow c = 588.143 \text{ mm} \]

\[ \beta = 6.51^\circ \]

\[ \beta = \beta_1 + \beta_2 \]

Assuming angle \( \beta_2 = 3^\circ \)

\[ \rightarrow \beta_1 = 3.51^\circ \]

\[ \text{FORMULARS FOR RIGHT TRIANGLES} \]

\[ \sin A = \frac{a}{c} = \left( \frac{\text{opposite}}{\text{hypotenuse}} \right) \quad (3) \]

From this formula, we can get:
a = c x Sin A

H_{min} = 2000 x Sin 3.51 = 122.445mm

The cars normally can go through with this height.

LAW OF COSINES

c^2 = a^2 + b^2 – 2abCos \gamma \quad (4)

From this formula, we can get:

\[ \cos \gamma = \frac{(a^2 + b^2 - c^2)}{(2ab)} \]

\[ \cos \alpha = \frac{(588.143^2 + 150^2 -450^2)}{(2 \times 588.143 \times 150)} \]

\[ \to \alpha = 19.90^\circ \]

5.3 Resolving cylinder force

The formula for the weight of the steel board:

http://zhidao.baidu.com/question/213729422.html

\[ W = 7.85 \times T \times A \]

*W = Weight [kg]
*T=Thickness [mm]
*A=Area \([m^2]\)

\[ \to W_{\text{max}} = 7.85 \times 10 \times 6 = 471 \text{ kg} \]
M = F x d \hspace{1cm} (5)

FORMULARS FOR RIGHT TRIANGLES

\[ \sin A = \frac{a}{c} = \frac{\text{opposite}}{\text{hypotenuse}} \] \hspace{1cm} (6)

From this formula, we can get:

\[ a = c \times \sin A \]

\[ \cos A = \frac{b}{c} = \frac{\text{adjacent}}{\text{hypotenuse}} \] \hspace{1cm} (7)

From this formula, we can get:

\[ b = c \times \cos A \]

\[ \Sigma O = 0 \]

\[ \rightarrow 2 \times F_c \times \sin 19.90 \times 588.143 - 471 \times 9.81 \times \cos 3.51 \times 1000 - 1700 \times 9.81 \times \cos 3.51 \times 2000 = 0 \]

\[ \rightarrow F_c = 94.67 \text{ KN} = 9467 \text{ daN} \]

5.4 Diameter of the piston and the rod of the cylinder

Pressure (P) used is 250 bar

The force produced by a double acting hydraulic piston on the rod side
can be expressed as

\[ F_1 = \frac{\pi}{4} \left( d_2^2 - d_1^2 \right) P_1 \]  \hspace{1cm} (8)

where

\( F_1 = \text{rod pull force (lb)} \)
\( d_1 = \text{rod diameter (inches)} \)
\( d_2 = \text{piston diameter (inches)} \)
\( P_1 = \text{pressure in the cylinder (rod side) (lf/in}^2) \)

The force produced opposite the rod can be expressed as

\[ F_2 = \frac{\pi}{4} d_2^2 P_2 \]  \hspace{1cm} (9)

where

\( F_2 = \text{rod push force (lb)} \)
\( P_2 = \text{pressure in the cylinder (opposite rod) (lf/in}^2) \)
\( d_{\text{piston}} = \sqrt{\frac{4 \times F}{P \times \pi}} = \sqrt{\frac{4 \times 94.67 \times 1000}{250 \times 10^5 \times \pi}} \)
\[ = 0.0694 \text{ m} = 69.4 \text{ mm} \]
\( d_{\text{rod}} = 69.4/\sqrt{2} = 49.1 \text{ mm} \)

### 5.5 Buckling Calculation

Factor of safety \((V) = 3\)
We choose the case 2: $S_k = l$

This is the length of the cylinder used $= 150\ mm = 15\ cm$.

\[
d_{rod} = 4\sqrt{(F_c \times S_k \times V/(\pi^2 \times E \times 0.0491))} = 4\sqrt{(9\ 467\ daN \times 15^2 \times 3/(\pi^2 \times 2.1\times10^6 \times 0.0491))} = 1.58\ cm = 15.8\ mm
\]

*S_k = free buckling length in mm*
*E = modulus of elasticity (2.1 x 10⁵ for steel) in N/mm²

Reading from the buckling table, the diameter chosen for the rod is 20 mm

For the piston is (√2) x 20 = 28.3 mm

Reading from the buckling table, the diameter chosen for the piston is 28 mm

http://wenku.baidu.com/view/b89d4171f242336c1eb95eb2.html

This figure shows the hydraulics data of the tank.
5.6 Hydraulic motor

Axial motor
The specification of motor: PM-O power motor

Figure 31

Hydraulic motor + Speed reducer
- Space is saved due to compact design.
- Cost is reduced due to integrated design.
- The output torque is quadrupled due to a built-in speed reducer (1/4).

Features
- Low-speed
- High-torque
- High-performance
- Power-saving power motor

Applications
Winch and hoist for vehicles, fishing machinery, construction machinery and various industrial machines

Specifications
- Release pressure 1.0MPa
- Max. flow rate 70 L/min
- Permissible back pressure 7.0 MPa
- Speed reduction ratio 1/4
- Load in radial direction 9 800 N
- Load in thrust direction 8 670 N


<table>
<thead>
<tr>
<th>Model</th>
<th>PM-070</th>
<th>PM-100</th>
<th>PM-120</th>
<th>PM-160</th>
<th>PM-170</th>
<th>PM-190</th>
<th>PM-240</th>
<th>PM-280</th>
<th>PM-310</th>
<th>PM-380</th>
<th>PM-410</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical displacement (cm³(rev))</td>
<td>206.0</td>
<td>205.6</td>
<td>204.0</td>
<td>203.6</td>
<td>197.6</td>
<td>194.0</td>
<td>192.0</td>
<td>190.0</td>
<td>187.6</td>
<td>185.0</td>
<td>183.6</td>
</tr>
<tr>
<td>Max. revolution (min⁻¹)</td>
<td>245</td>
<td>230</td>
<td>180</td>
<td>145</td>
<td>110</td>
<td>95</td>
<td>75</td>
<td>60</td>
<td>55</td>
<td>50</td>
<td>45</td>
</tr>
<tr>
<td>Rated torque (N·m)</td>
<td>440</td>
<td>420</td>
<td>340</td>
<td>300</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Max. torque (N·m)</td>
<td>530</td>
<td>732</td>
<td>1024</td>
<td>1200</td>
<td>1300</td>
<td>1300</td>
<td>1300</td>
<td>1300</td>
<td>1300</td>
<td>1300</td>
<td>1300</td>
</tr>
<tr>
<td>Rated Pressure (MPa)</td>
<td>15.5</td>
<td>15.5</td>
<td>15.5</td>
<td>15.5</td>
<td>15.5</td>
<td>15.5</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Max. pressure (MPa)</td>
<td>19.0</td>
<td>19.0</td>
<td>19.0</td>
<td>18.5</td>
<td>17.0</td>
<td>12.0</td>
<td>12.0</td>
<td>8.0</td>
<td>8.0</td>
<td>7.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Note: When a rectangular flange for installation is selected, 3 kg must be added to the above weight.

Figure 32

Mechanical and Volumetric efficiency calculations

-Mechanical efficiency ($\eta_m$) = Torque/ (D*P) % = 1 024*100/ (394*15.5) % = 16.77%
-volumetric efficiency calculation ($\eta_v$)

$$\eta_v = D*P*\eta_m/ (20*\pi) \% = 394*15.5*0.1677*100/ (20*\pi) = 1 629.98\%$$

5.7 Flow rate calculation

Q = Flow rate
N = Speed (revolution/min.)
$\eta_v$ = Volumetric efficiency
\[ D = \text{Displacement} \]

\[ Q = \frac{D \cdot n}{1000 \cdot \eta_v} \text{ litres/min} \]

\[ Q = \frac{394 \cdot 180}{1000 \cdot 16.2998} = 4.35 \text{ litres/min.} \]

**Tank size:**

The accepted rule for a tank = (3 to 5) * Q

Therefore the size of the tank = 5 * 4.35 = 21.75 litres

**Hydraulic fluid temperature (Temperatures/Housing cooling)**

Excessive system temperature reduces the life of the shaft seal and can lower the oil viscosity below the recommended level. A system temperature of 60 °C and a drain flow temperature of 90 °C must not be exceeded. Cooling/flushing of the motor housing can be needed to keep the drain flow temperature at an acceptable level. The range of fluid temperature is between -20 °C and 80 °C

---

### 6 Cost estimation

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Amount in Euros (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Electrical connection 0V</td>
<td>50€</td>
</tr>
<tr>
<td>1</td>
<td>Electrical connection 24V</td>
<td>50€</td>
</tr>
<tr>
<td>1</td>
<td>Pump unit</td>
<td>500€</td>
</tr>
<tr>
<td>4</td>
<td>2-way flow control valve</td>
<td>160€*4 = 640€</td>
</tr>
<tr>
<td>4</td>
<td>4/n way valve</td>
<td>300€*4 = 1200€</td>
</tr>
<tr>
<td>4</td>
<td>Check valve</td>
<td>60€*4 = 240€</td>
</tr>
<tr>
<td>4</td>
<td>Filter</td>
<td>350€*4 = 1400€</td>
</tr>
<tr>
<td>2</td>
<td>Flow divider valve</td>
<td>150€*2 = 300€</td>
</tr>
<tr>
<td>4</td>
<td>Double acting cylinder</td>
<td>450€*4 = 1800€</td>
</tr>
<tr>
<td>Item Description</td>
<td>Price</td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------------------------------------</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>with shock adsorber at stroke end</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Pushbutton (make)</td>
<td>60€*4</td>
<td></td>
</tr>
<tr>
<td>4 Valve solenoid</td>
<td>120€*4</td>
<td></td>
</tr>
<tr>
<td>4 Check valve with pilot control</td>
<td>350€*4</td>
<td></td>
</tr>
<tr>
<td>8 Hose with quick-action coupling</td>
<td>150€*8</td>
<td></td>
</tr>
<tr>
<td>4 Member of bars, pins, bolts and nuts</td>
<td>450€*4</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous expenses</td>
<td>2 000€</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>13 300€</strong></td>
<td></td>
</tr>
</tbody>
</table>

### 6.1 References

7 Conclusions

The above discussion has evaluated the parking shaft could save the space successfully and cost lower than other equipment. Nowadays in China, save space is more and more important. The idea of the design is suitable for the Chinese social situation. The shaft is suitable for most families and it can be concluded that the new product developed has a big opportunity to conquer the marketplace.

At this half year for the thesis, we get more experience for the how to use the mechanical technology in real life, especially in hydraulic design.