MEMS 1029
Mechanical Design 2

Project 2

What's If – Charger?

March 18 2022

Recording Link
Formal PDF Link

Group 12
Puhang Cai, Ziang Cao, Yuming Gu, Mingze Cai, Yoosup Shin

Contribution

Table 1. Work distribution

Task	Time (hrs)	Member
/// Overall Managements ///		
Project Orgnization	5	ZIC
Project PDf Wrtiting	7	ZIC
Professionalism Check	2	MIC, PUC
/// Presentation ///		
Pre Slide	4	PUC, YOS, MIC, ZIC
CAD animation	1	YUG, YOS
Video editing	2	MIC, YUG
Video Recording -- All Part	2	YOS
/// Design Anlysis ///		
Normal Spring Anlysis	4	ZIC, YOS
Torsion Spring Analysis	3	PUC
Rotor Spring Analysis	10	PUC, YOS
Gear Train Design	3	MIC, ZIC
/// CAD modeling ///		
Hand Crank CAD PickUP	1	ZIC
Spring + Gear CAD PickUP	3	YUG, PUC
SolideWorks Assembly	15	YUG
/// Post-design ///		
Bill of Material	2	PUC, MIC
/// Formal Calculations ///		
Free Body Diagram + sketch	2	ZIC
Spring Calculations	3	PUC
Gear Train Calculations	2	MIC

Overview

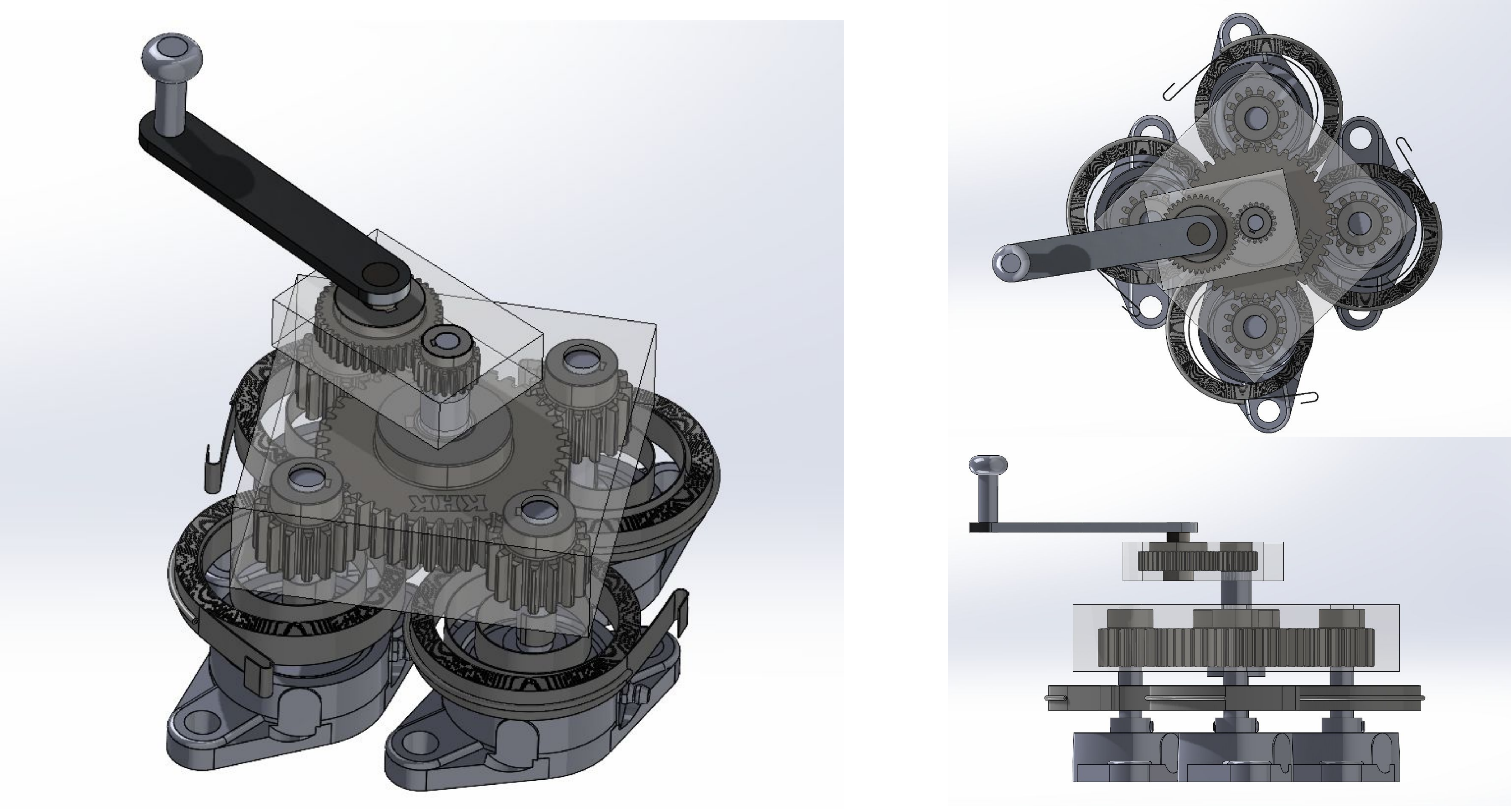


Figure 1. The overview of the product. There are shells at the outside of each spring and each shaft has 1 spring on it. There are 4 bearings at the end of the shaft.

Objectives

We try to design a phone charger that can support manual energy input and mechanical energy storage in this project. The requirements and constraints are shown below:

- **Device must be capable of storing 10 Watt-hours of energy.**
- **Energy storage must be done using springs.**
- **Input power must come from a human-powered hand-crank.**
- **Device must have a gearbox and gear train.**
- **The product needs to be as small as possible**

Design and Analysis

Normal Spring Analysis

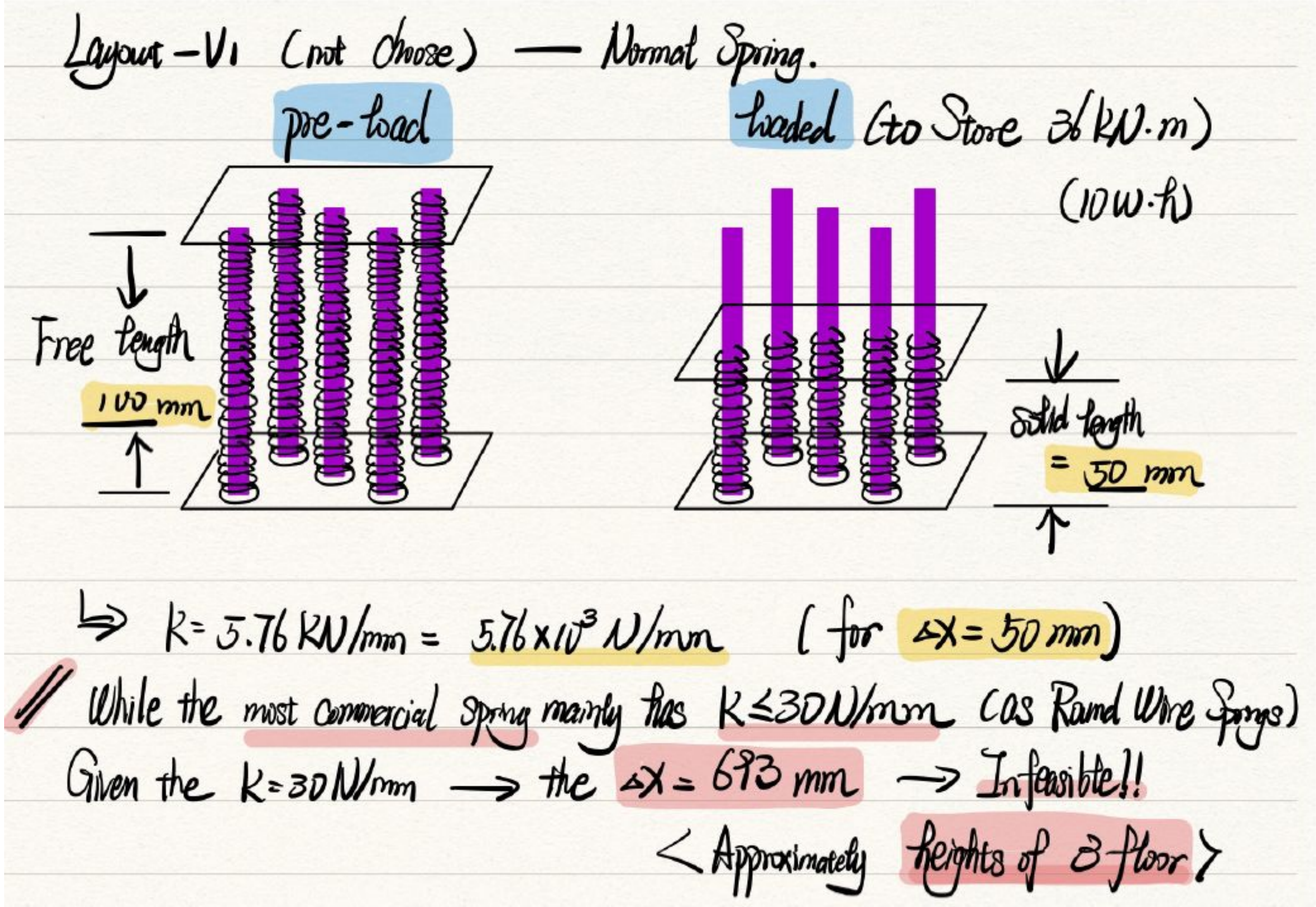
We start from the round wire spring. As making a real world-product, instead of solving a textbook question: we simplify the design by applying "Over-a-rod" scenario -- which to get rid of the buckling, we add sticks inside of the wire.

However, even with a rob, the round wire spring would requires 5000 N/mm (a 100 times larger K than most commercial one), or 7m of delta_x (Height of 3 floor) to store the enough energy. The following figure shows the key scenarios.

Design and Analysis

Normal Spring Analysis

Detail for calculation:
https://github.com/ice-bear-git/_MEMS1029_DesignII_onGithub/blob/main/Project/Project2/Submission/FormalAnalysis/Screenshot/Layout-v1.PNG



Design and Analysis

Torsion Spring Analysis

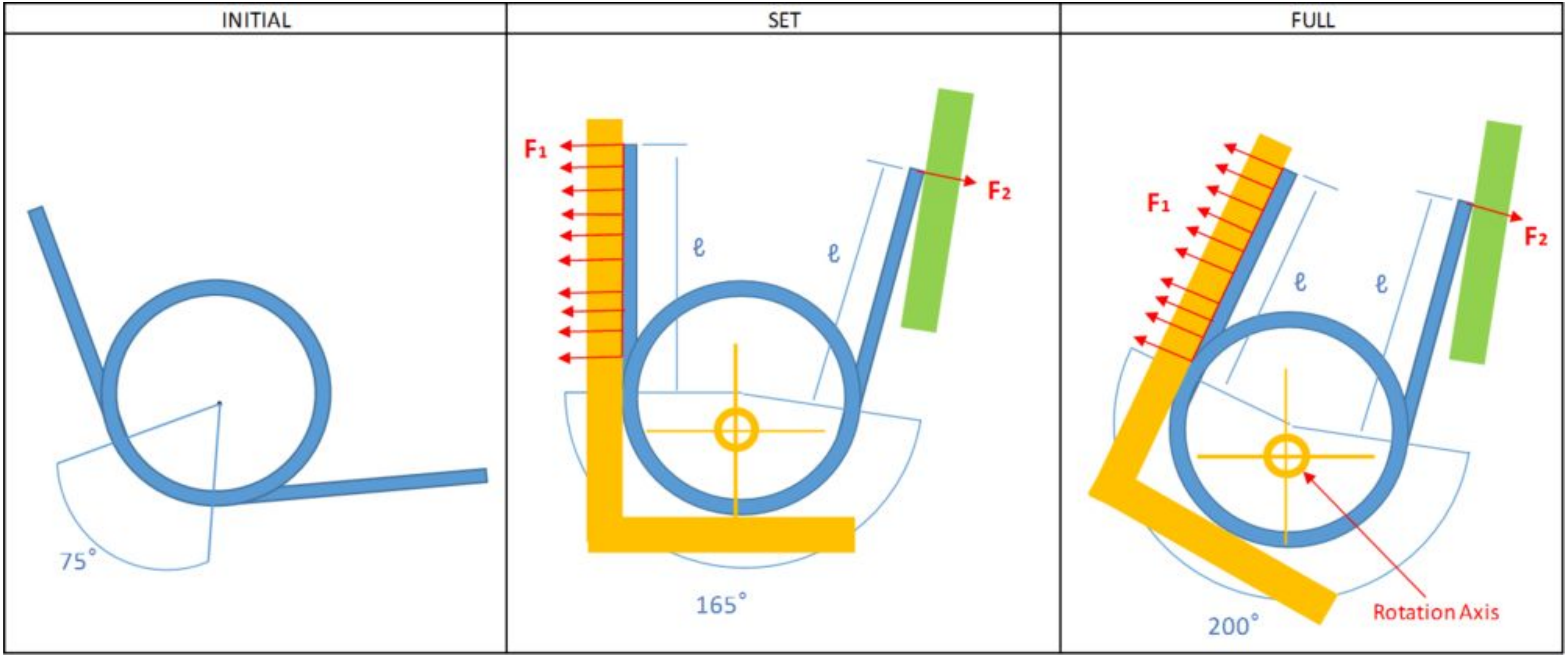


Figure 2. Free Body Diagram for Torsion Spring. [1]

Design and Analysis

Torsion Spring Analysis

We choose music wire for torsion spring. The tensile strengths for the wire can be determined by using followed equation.

$$S_{ut} = \frac{A}{d^m}$$

For music wire, d is wire diameter. $A = 201 kpsi \cdot in^m$ and $m = 0.145$. $S_y = 0.78 S_{ut}$

The spring index $C = \frac{D}{d}$. Where D is the mean coil diameter.

The bending stress-correction $K_i = \frac{4C^2 - C - 1}{4C(C-1)}$

Then we can find the maximum torque $M_{max} = (Fr)_{max} = \frac{\pi d^3 S_y}{32 K_i}$

The spring rate is $k' = \frac{d^4 E}{64 D N_a}$

Where Na is the active number of turns.

Design and Analysis

Torsion Spring Analysis

The equation for θ is

$$\theta = \frac{64MDN_a}{d^4E}$$

The maximum energy can be stored in torsion,

$$U = \frac{1}{2}k'\theta^2$$

We can find the number of springs needed by dividing the energy required by the maximum energy one spring can store.

Design and Analysis

Torsion Spring Analysis

We take 360° Deflection Angle spring from Mcmaster as an example.

OD	For Shaft Dia.	Wire Dia.	Leg Lg.	Number of Coils	Spring Lg. @ Max. Torque	Max. Torque, in.-lbs.	Material	Pkg. Qty.		Pkg.
360° Deflection Angle										
Left-Hand Wound										
1.755"	1.188"	0.135"	4"	12.5	2.025"	42.86	Music-Wire Steel	1	9271K136	$6.89

Maximum energy of a spring can store:

$$U = \frac{1}{2}k'\theta^2 = \frac{1}{2}\frac{d^4E}{64DN_a} \times \left(\frac{64MDN_a}{d^4E}\right)^2 = \frac{1}{2}\frac{64DN_aM^2}{d^4E} = 161lbf \cdot in = 18.2N \cdot m$$

Therefore, we need about 200 of torsion springs to store 10 Watt-hours of energy. The product would become expensive and complex if using this kind of spring.

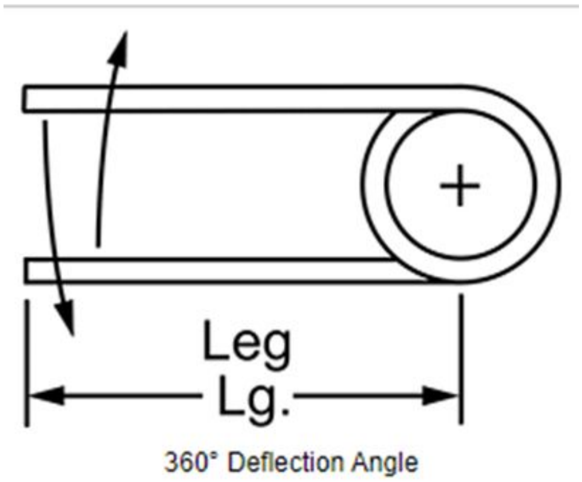
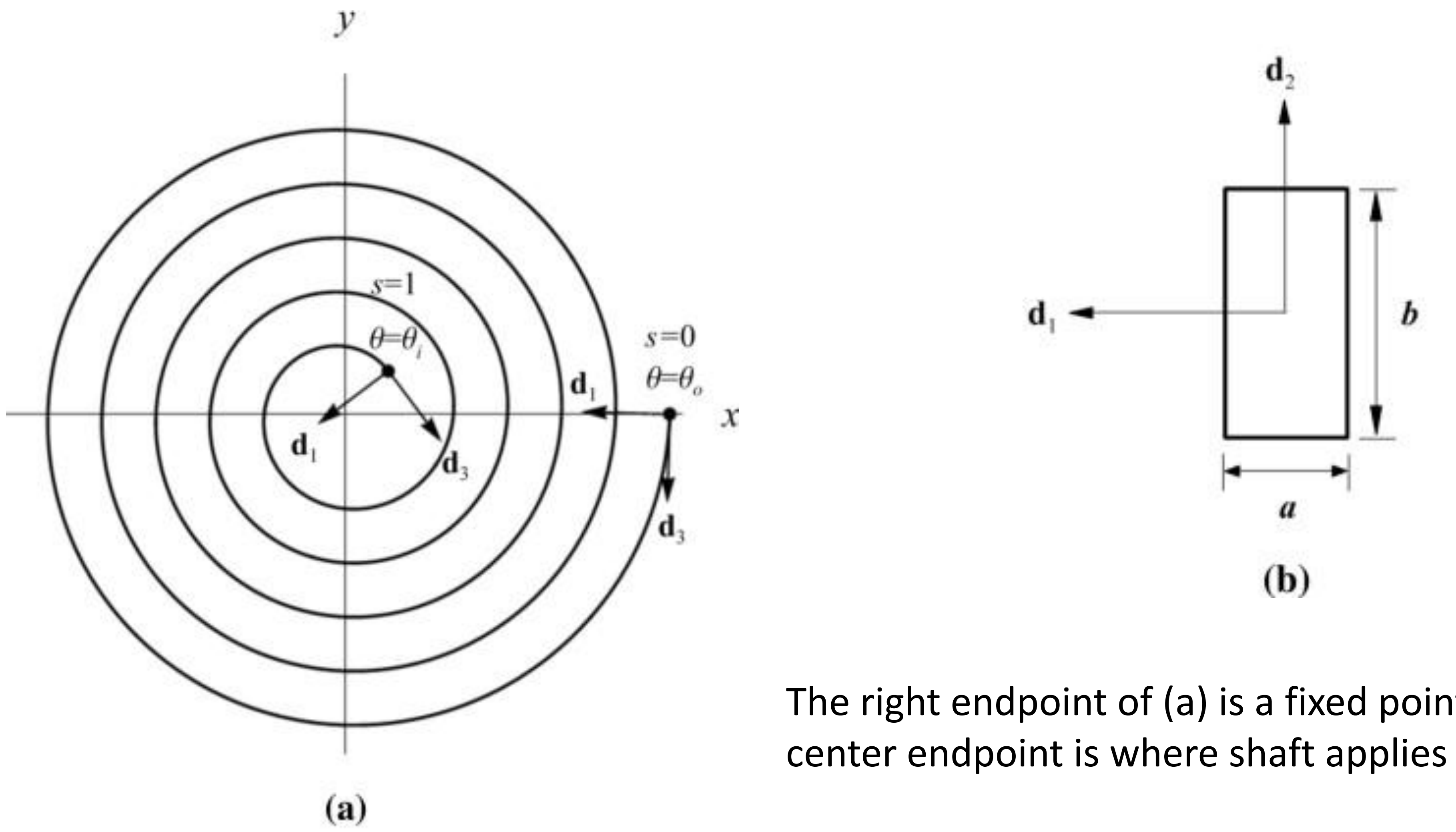


Figure 3. Torsion spring from Mcmaster

Link for this spring: https://www.mcmaster.com/torsion-springs/torsion-springs-5/

Design and Analysis

Flat Spiral Spring Analysis



The right endpoint of (a) is a fixed point and the center endpoint is where shaft applies force

Figure 4. Free Body Diagrams for Rotor Spring [2]

Design and Analysis

Flat Spiral Spring Analysis

Table 2. Symbols and units used in calculations

Symbol	Meaning of Symbol	Unit
E	Longitudinal elastic modulus	N/mm^2
b	Material width	mm
t	Plate thickness	mm
l	Total length	mm
M	Moment	N･mm
k	Spring constant	N･mm/rad
σ	Stress	N/mm^2

Design and Analysis

Flat Spiral Spring Analysis

The basic formula for calculating the spring constant when winding is given by the following formula.

$$k = \frac{Ebt^3}{12l}$$

The torque delivered (M) per turn (360°) is expressed by the following formula, where 360° is represented as 2π.

$$M = 2\pi k$$

The turned angle can be expressed as:

$$\theta = \frac{Ml}{EI} = \frac{12Ml}{Ebt^3}$$

The energy stored in the spring for 1 turn is

$$U = \frac{1}{2}M\theta = \frac{1}{2}\frac{M^2 l}{EI} = \frac{6M^2 l}{Ebt^3}$$

Design and Analysis

Flat Spiral Spring Analysis

Table 3. Results by using the spring from Amico (link in the **Cost** Page) and assume the spring turn 10 turns.

Meaning of Symbol	Unit	Flat Spiral Spring	
Longitudinal elastic modulus	N/mm^2	E	206000
Material width	mm	b	10
Plate thickness	mm	t	1.6
Total length	mm	l	1540
Spring constant	N･mm/rad	k	456.5887
Torque	N･mm	M	28688.32
Stress	N/mm^2	sigma	6723.824
	rad	theta	62.83185
	N･mm	energy	901270.1
Number of spring required		**Quantity**	**3.994363**

Design and Analysis

Spring Arrangement

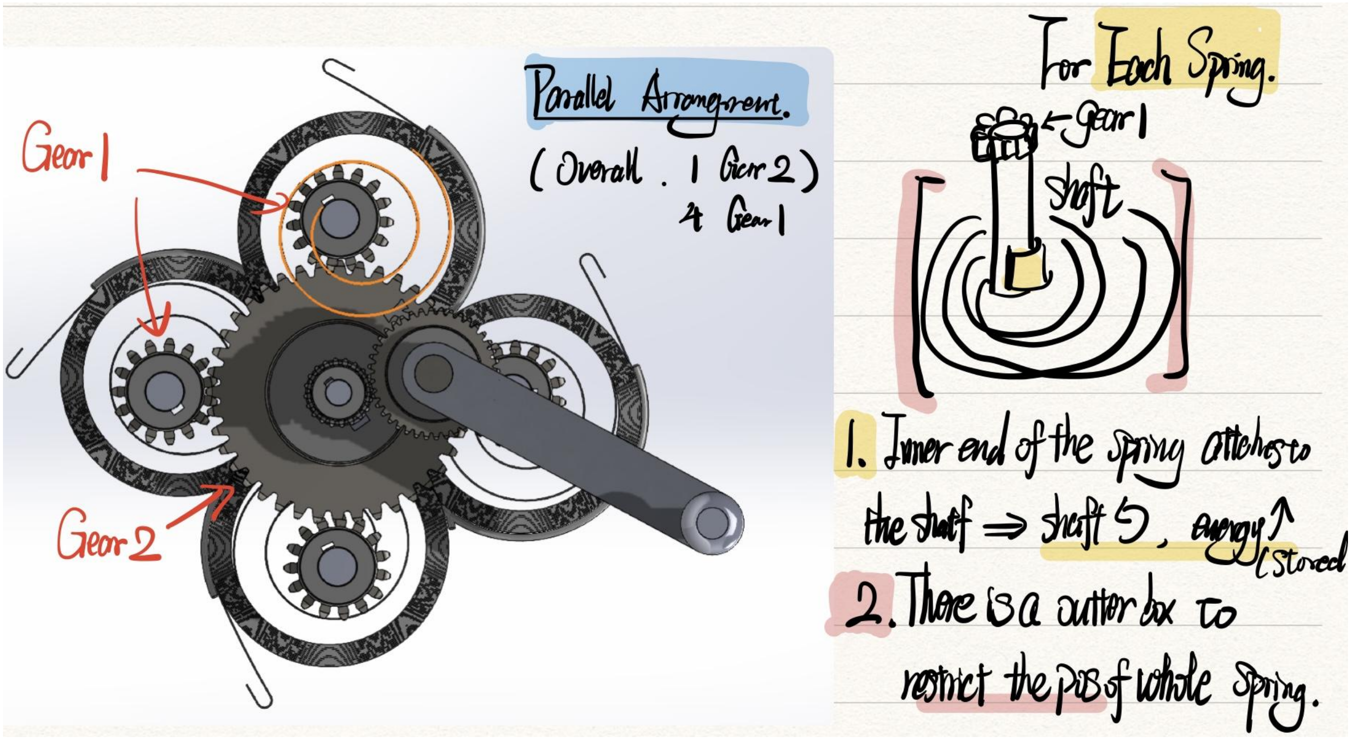
Parallel Arrangement (Overall)

1. Four Gear 1 is connected to the center of each spring to transport the energy from the input to the springs

2. Each spring is evenly distributed to the four corners. (for bending moment cancelation, and size minimization.)

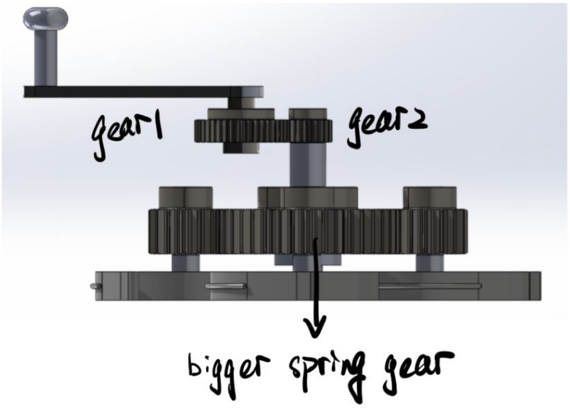
Outer Box Restriction (Individuals)

1. Use the outer box to restrict the position of the spring. That is essential for the energy storage part.
   [As it's not the key point for the analysis, we didn't draw it in SolidWorks. However, we implements the bearing in CAD that holds the position of the shafts.]



Design and Analysis

Gear Train Analysis



Torque needs

$$8.3\frac{in\cdot lb}{sping}\times 100spring\times 1.356\frac{N\cdot m}{feet\cdot lb}\times\frac{1}{12}\frac{feet}{in}=93.79N\cdot m$$

A man can provide a force

$$F_{max}=500N$$

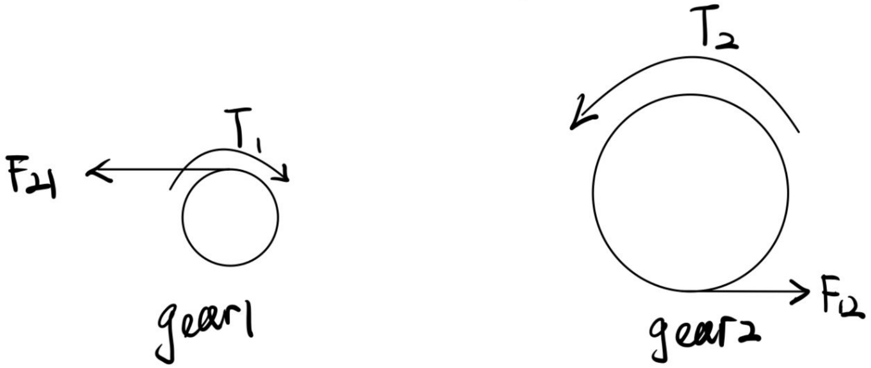


Figure 5. FBD of the gears

Torque applied to the first gear Gear 1 is

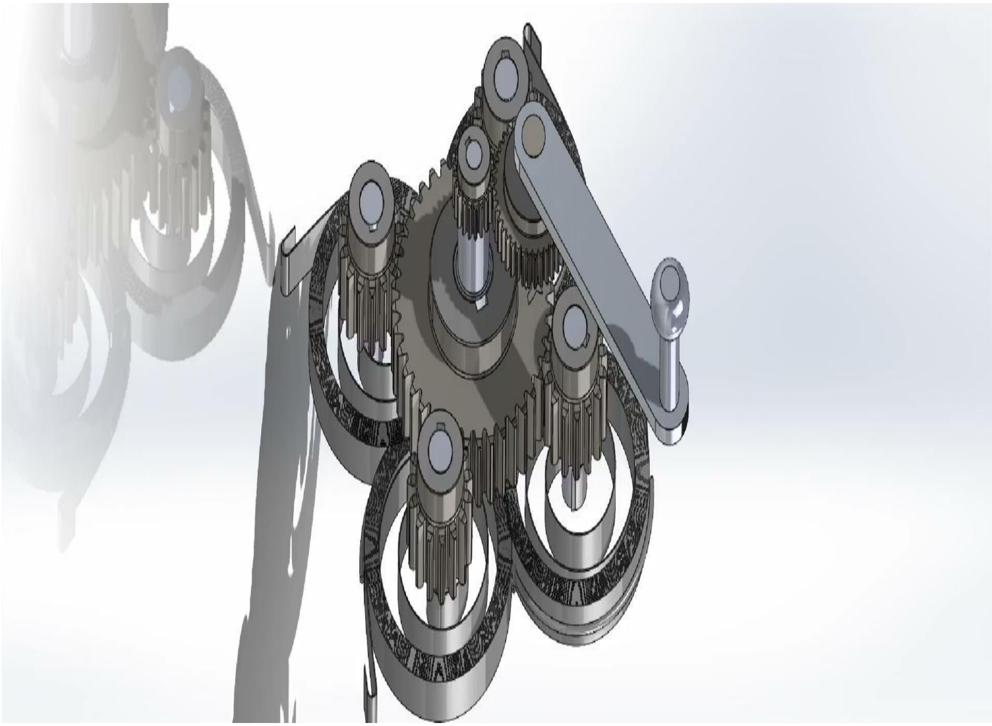
$$T_1=F\times d=50\ N\cdot m$$

Gear 2 is connected to the bigger spring gear through a stick, so they have a same torque

$$F_{21}=\frac{T_1}{R_1}\qquad T_2=F_{12}\times R_2=F_{21}\times R_2=50\times\frac{R_2}{R_1}=100N\cdot m>93.79N\cdot m$$

Solid Model & Engineering Drawing

Overview



Video 1. The assembly video and motion video for the product. Note that in realistic the hand-crank rotate along with the gear and there are several rotor springs shells and bearings not shown in the video.

Solid Model & Engineering Drawing

Explosion View

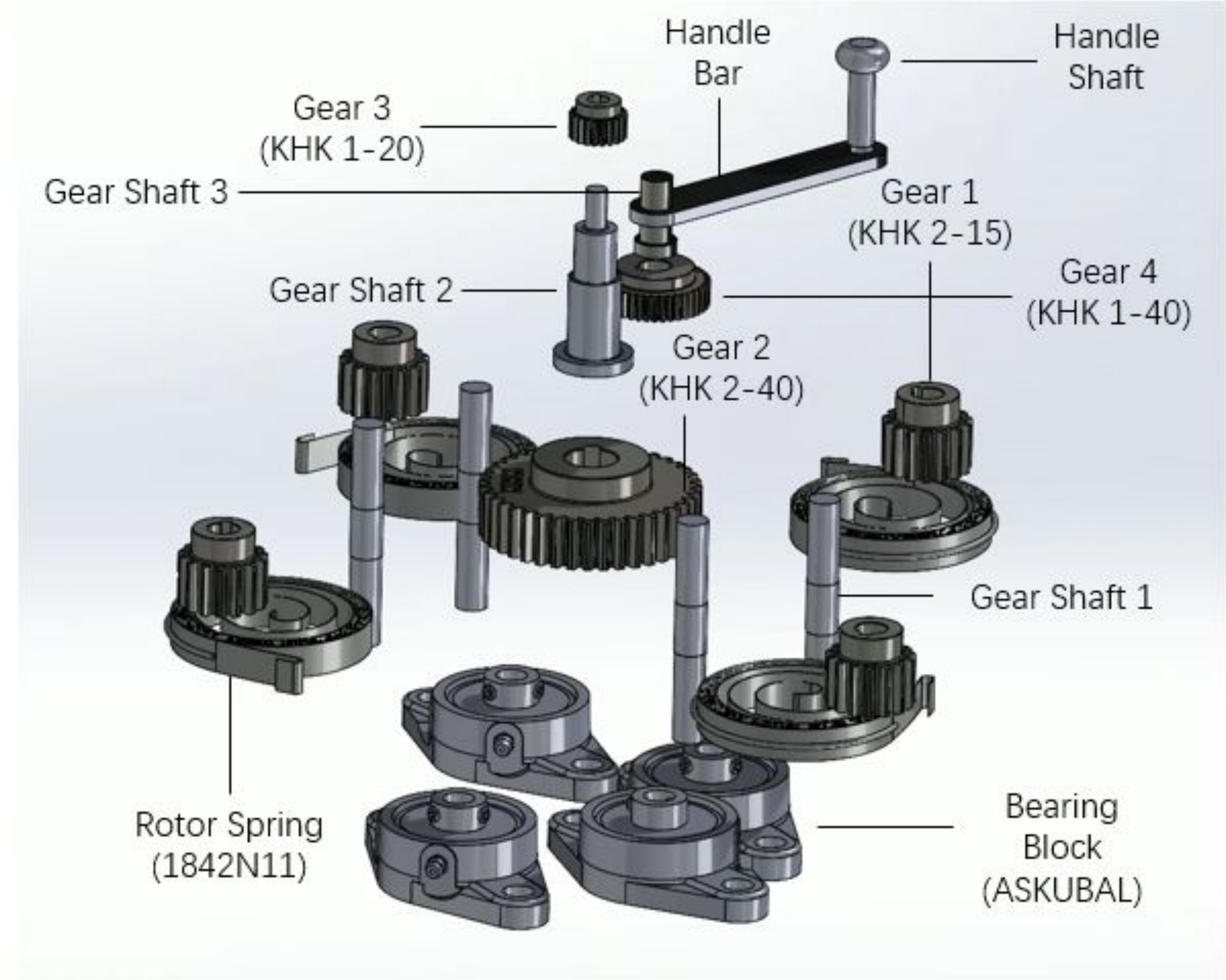
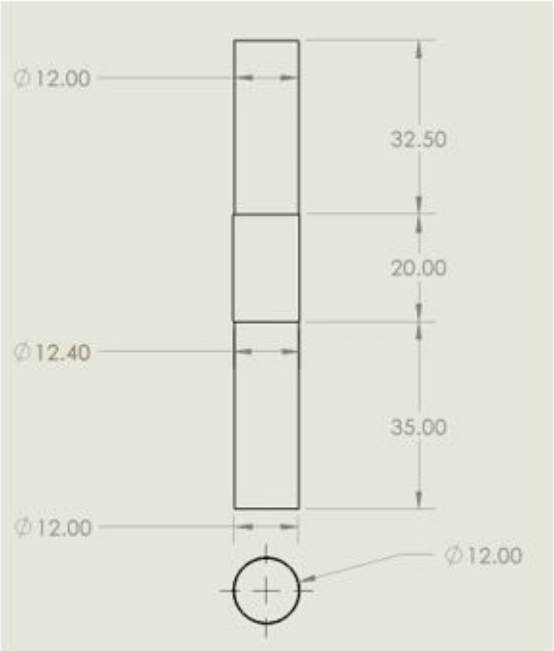


Figure 6. Explosion View for the product

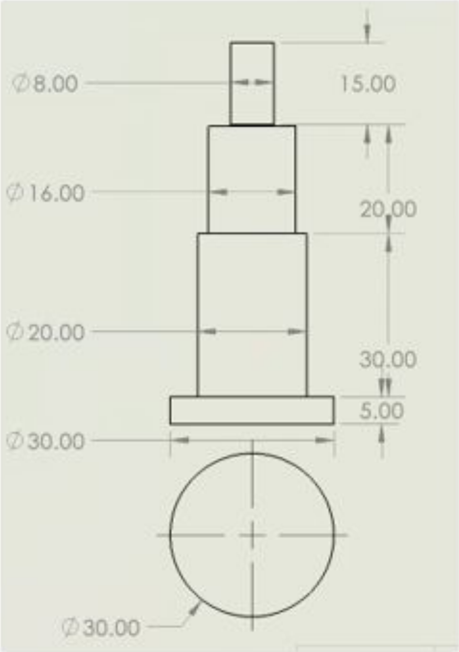
Solid Model & Engineering Drawing

Gear Box

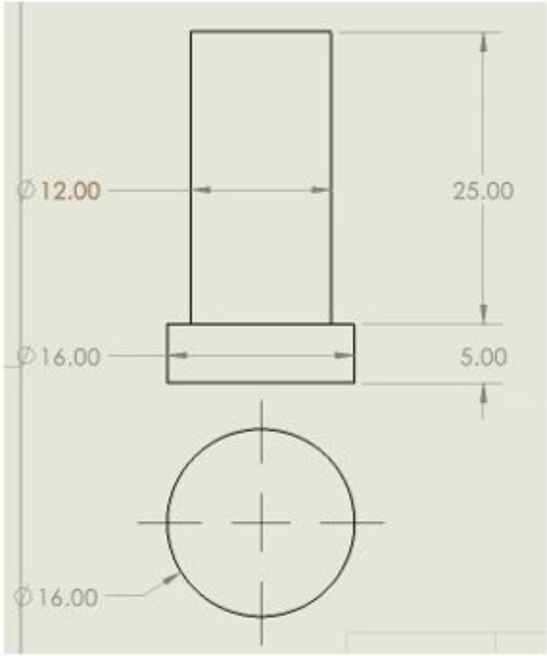
Gear Shaft 1 (Designed)



Gear Shaft 1



Gear Shaft 2



Gear Shaft 3

Figure 7. The Engineering Drawing for the gear shaft

Solid Model & Engineering Drawing

Gear Box

Gear 1 (KHK 2-15)
https://www.khkgears.us/catalog/product/MSGA2-15

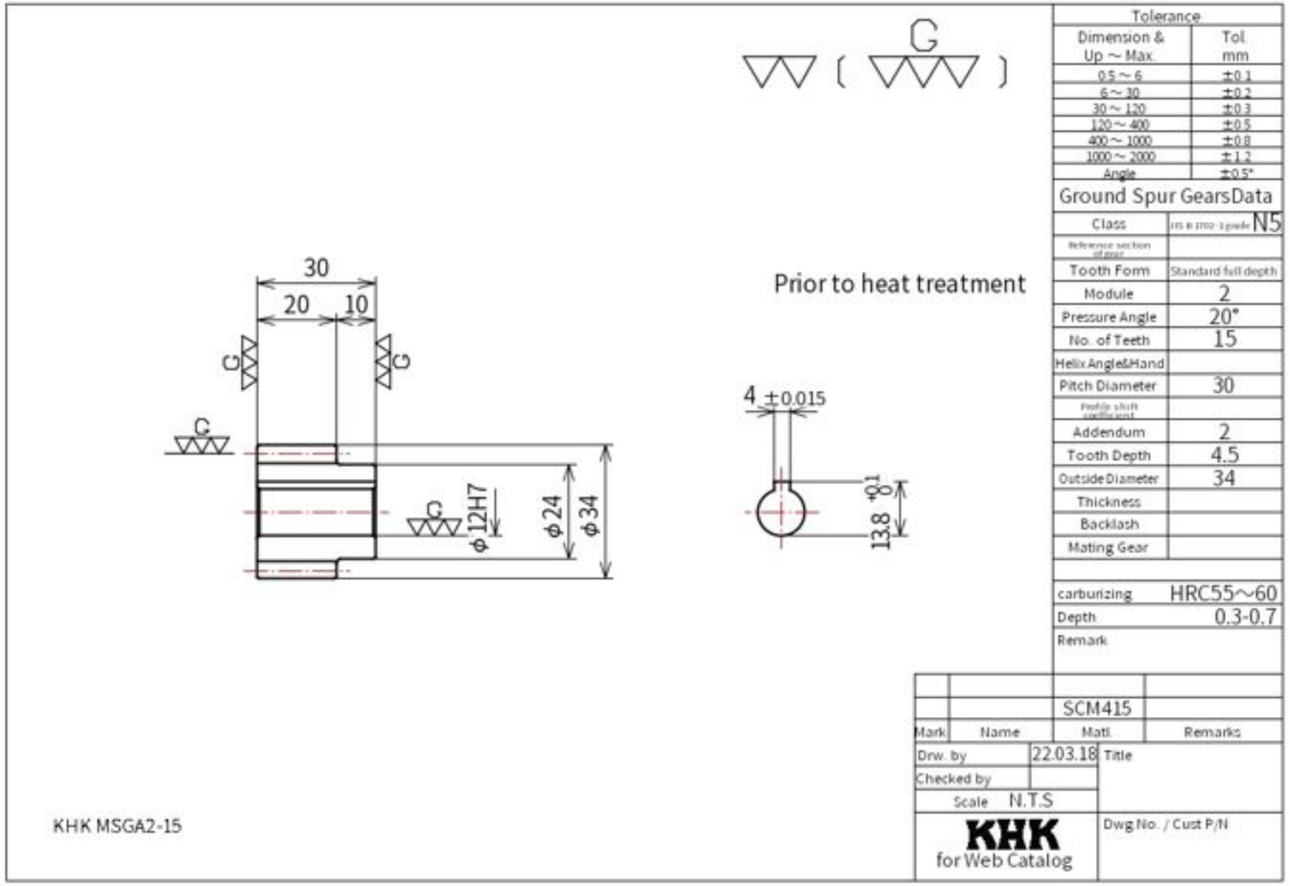


Figure 8. This is the engineering drawing for the small gear connected to the spring

Solid Model & Engineering Drawing

Gear Box

Gear 2 (KHK 2-40)
https://www.khkgears.us/catalog/product/MSGA2-40

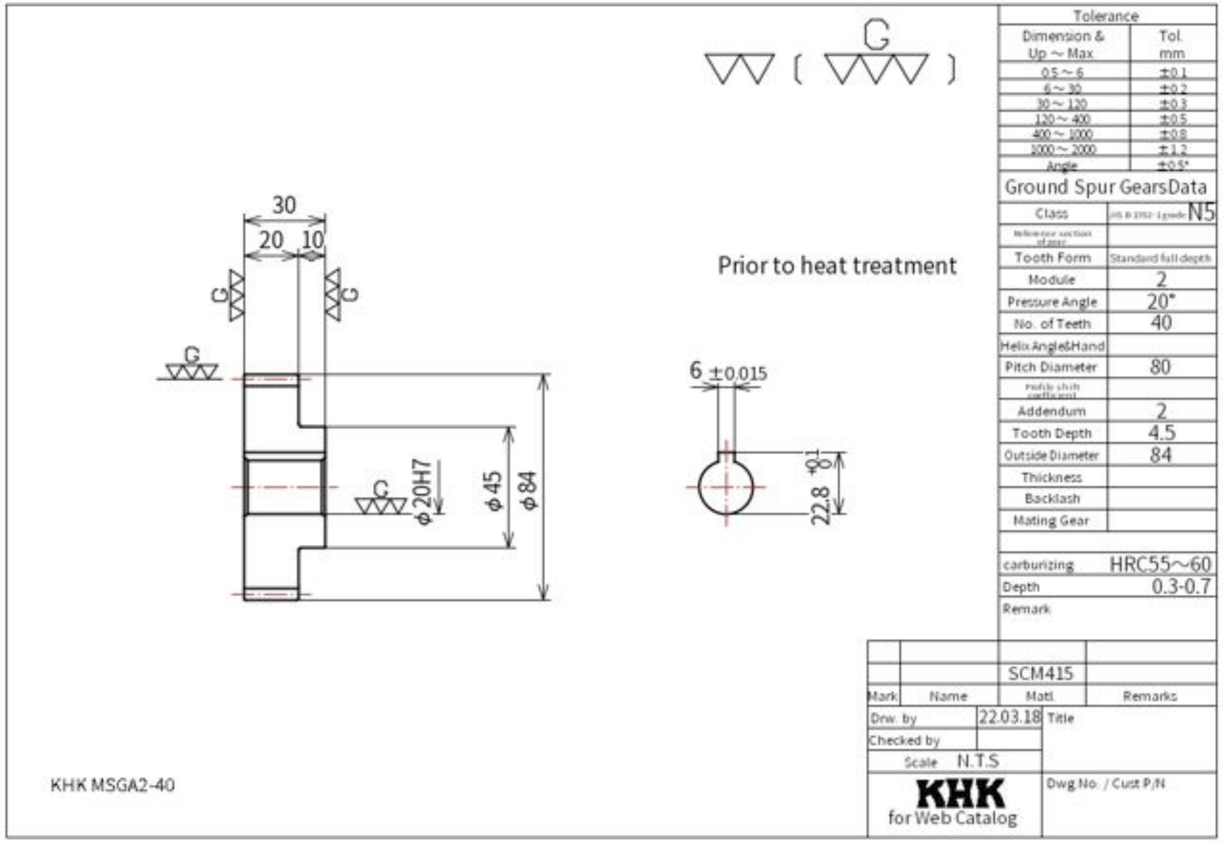


Figure 9. The engineering drawing for the gear connected to gear 1.

Solid Model & Engineering Drawing

Gear Box

Gear 3 (KHK 1-20)
https://www.khkgears.us/catalog/product/MSGA1-20

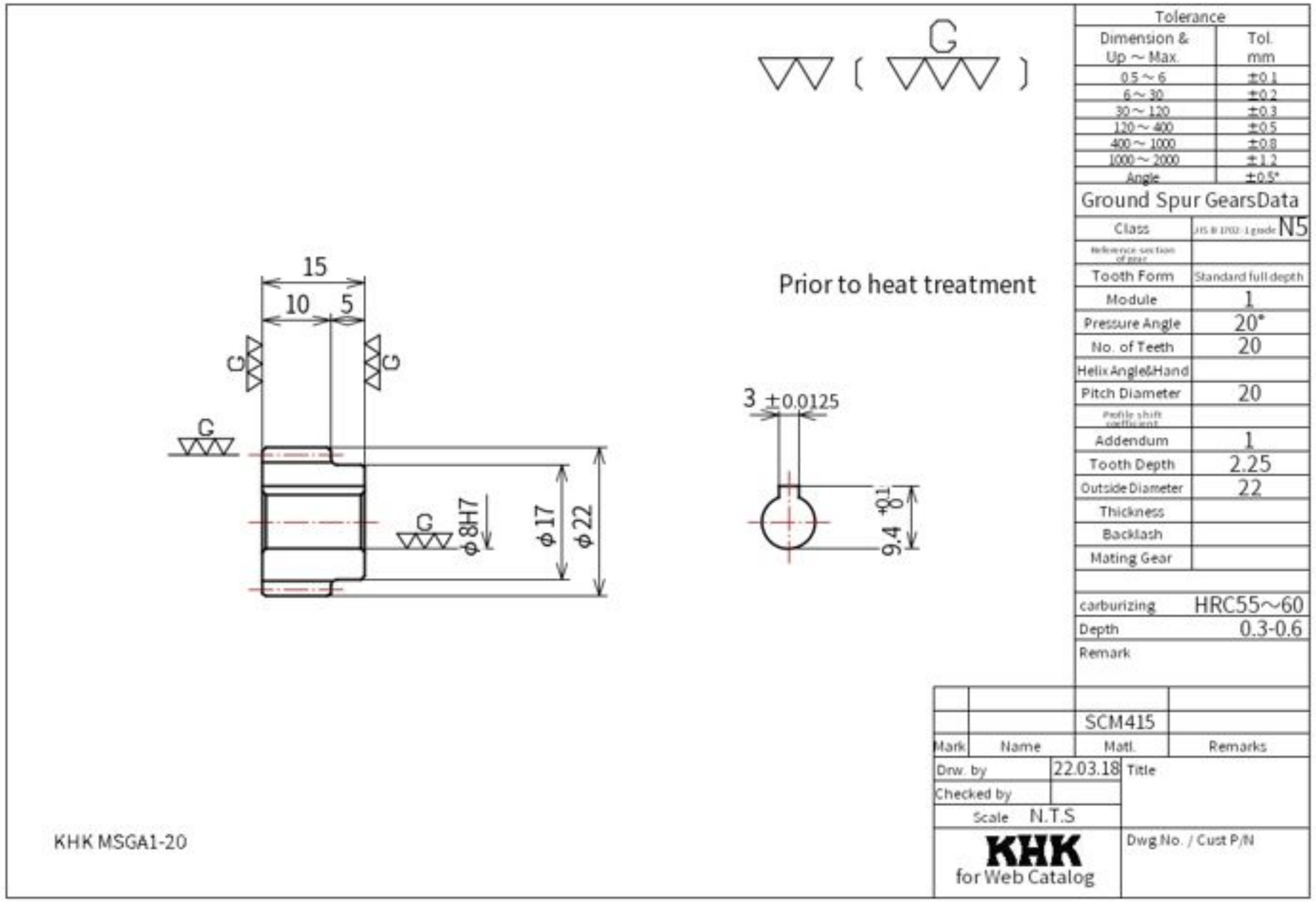


Figure 10. The engineering drawing for the gear connect to gear 4 and gear 3.

Solid Model & Engineering Drawing

Gear Box

Gear 4 (KHK 1-40)
https://www.khkgears.us/catalog/product/MSGA1-40

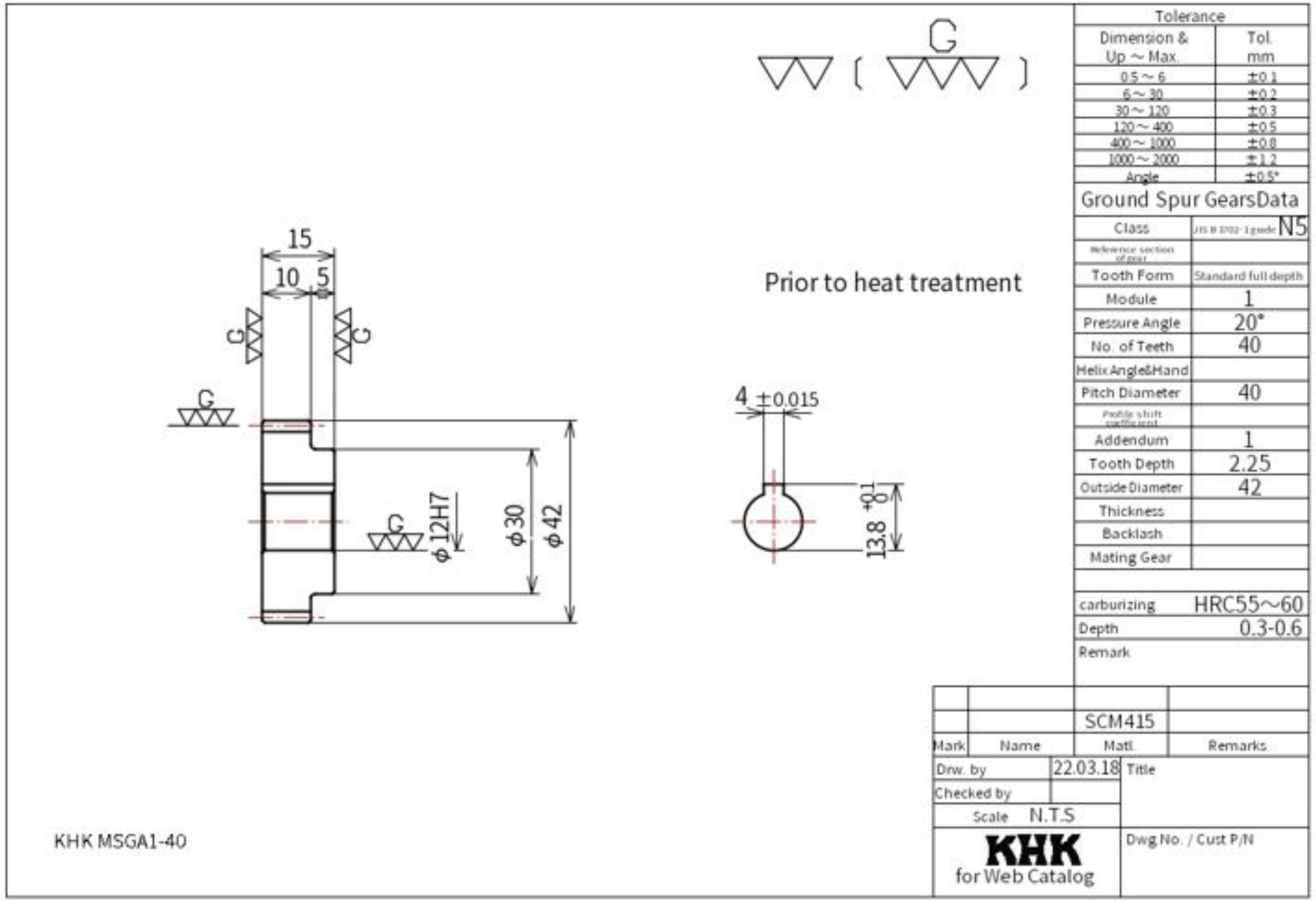
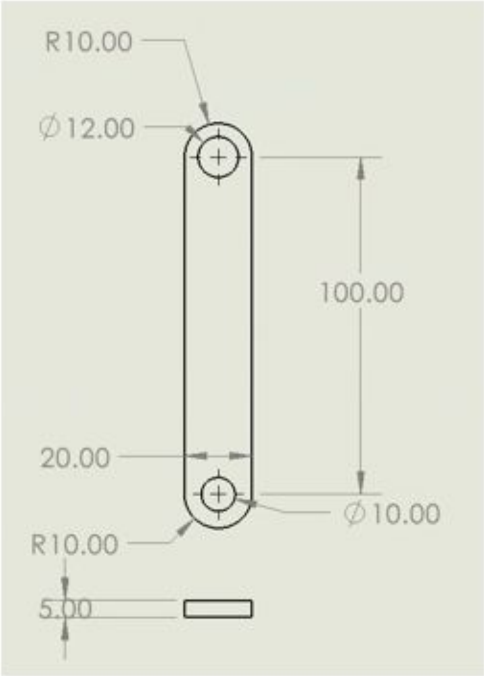


Figure 11. The engineering drawing for the gear connect to the hand-crank

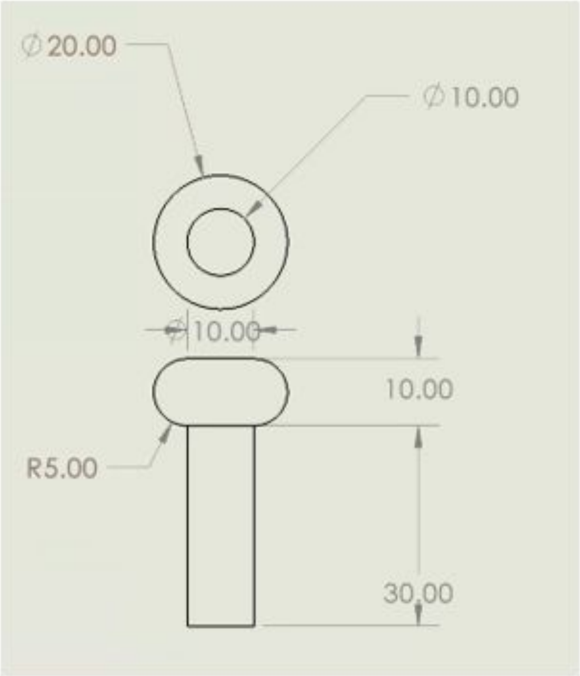
Solid Model & Engineering Drawing

Hand-crank

Handlebar & Handle shaft (Designed)



Handlebar



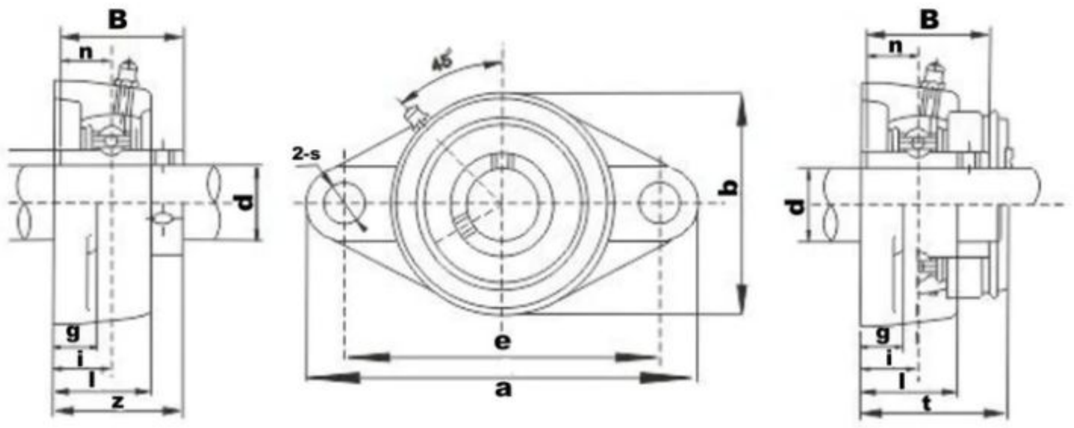
Handle shaft

Figure 12. The engineering drawing for the hand-crank

Solid Model & Engineering Drawing

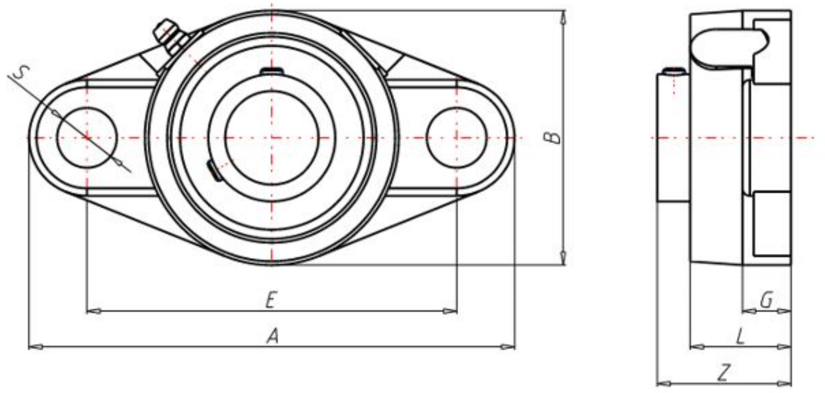
Energy Storage Setup

Bearing Block (ASKUBAL)
https://b2b.partcommunity.com/3d-cad-models/sso/ucfl-ucfl-200-ask-kugellagerfabrik-artur-seyfert?info=askubal%2Fbearing_units%2Fsquare_flange_units%2Fcast_iron_version%2Fucfl_200_asmtab.prj



Unit No.	Dimension mm in.											Bolt Size mm inch	Bearing No.	Housing NO.	Weight (kg)
	d	a	e	i	g	l	S	b	z	B	n				
UCFL206-20	1-1/4"	5-13/16	4-39/64"	45/64"	1/2"	1-7/32"	5/8"	2-5/32"	1-19/32"	1.5"	0.626"	M14 1/2"	UC206-20	FL206	0.85

Figure 13(a). The bearing used in the real product



S s [mm]	B b [mm]	Z [mm]	BI Bi [mm]	N n [mm]	BS Mounting screws	TD Load rating dynamic C [kN]	TS Load rating static C0 [kN]	GEW Weight [kg]
12	60	33.3	31.0	12.7	M10	12.80	6.60	0.45

Figure 13(b). The bearing used in the CAD model

Solid Model & Engineering Drawing

Energy Storage Setup

Figure 14(a). The spring used in the real product

Rotor Spring (1842N11)
https://www.mcmaster.com/rotary-springs/rotor-springs/

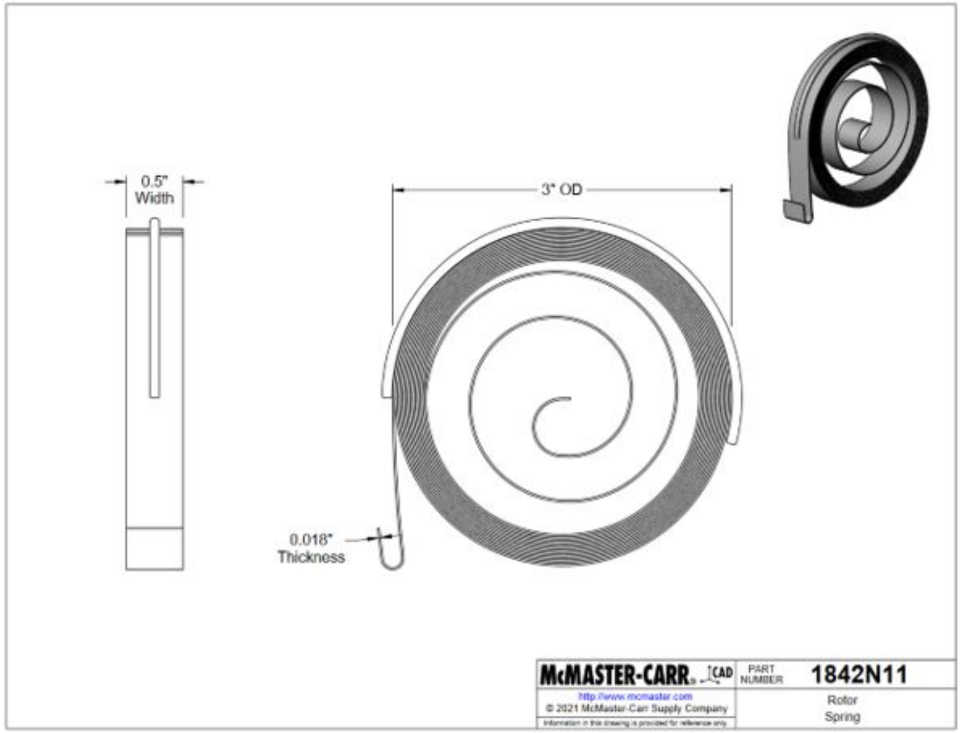


Figure 14(b). The spring used in the CAD model

Cost

Name	Part Numbers	Vendors	Quantity	Cost
Rotor Spring	UXCELL Drill Press Spring Drill Press Quill Feed Return Coil Spring Assembly Spring Steel Chemical Blackening Finish 1PCS Size 3	Amico	4	$38.12
Shaft	2900A367	McMaster-Carr	4	$35.24
Hand-crank	90480	Compass Health	1	$37.46
Gear 1	KHK MSGA1-20, Module 1, 20 Tooth, Ground Alloy Steel Spur Gears	KHK	1	$55.17
Gear 2	KHK MSGA1-40, Module 1, 40 Tooth, Ground Alloy Steel Spur Gears	KHK	1	$82.60
Gear 3	KHK MSGA2-40, Module 2, 40 Tooth, Ground Alloy Steel Spur Gears	KHK	1	$118.64
Gear 4	KHK MSGA2-15, Module 2, 15 Tooth, Ground Alloy Steel Spur Gears	KHK	4	$228.16
Bearing	UCFL206-20 Pillow Block Flange Mounted Bearing 1-1/4" Inch Bore	PGN Bearing	4	$35.8
Total				$631.19

Feasibility

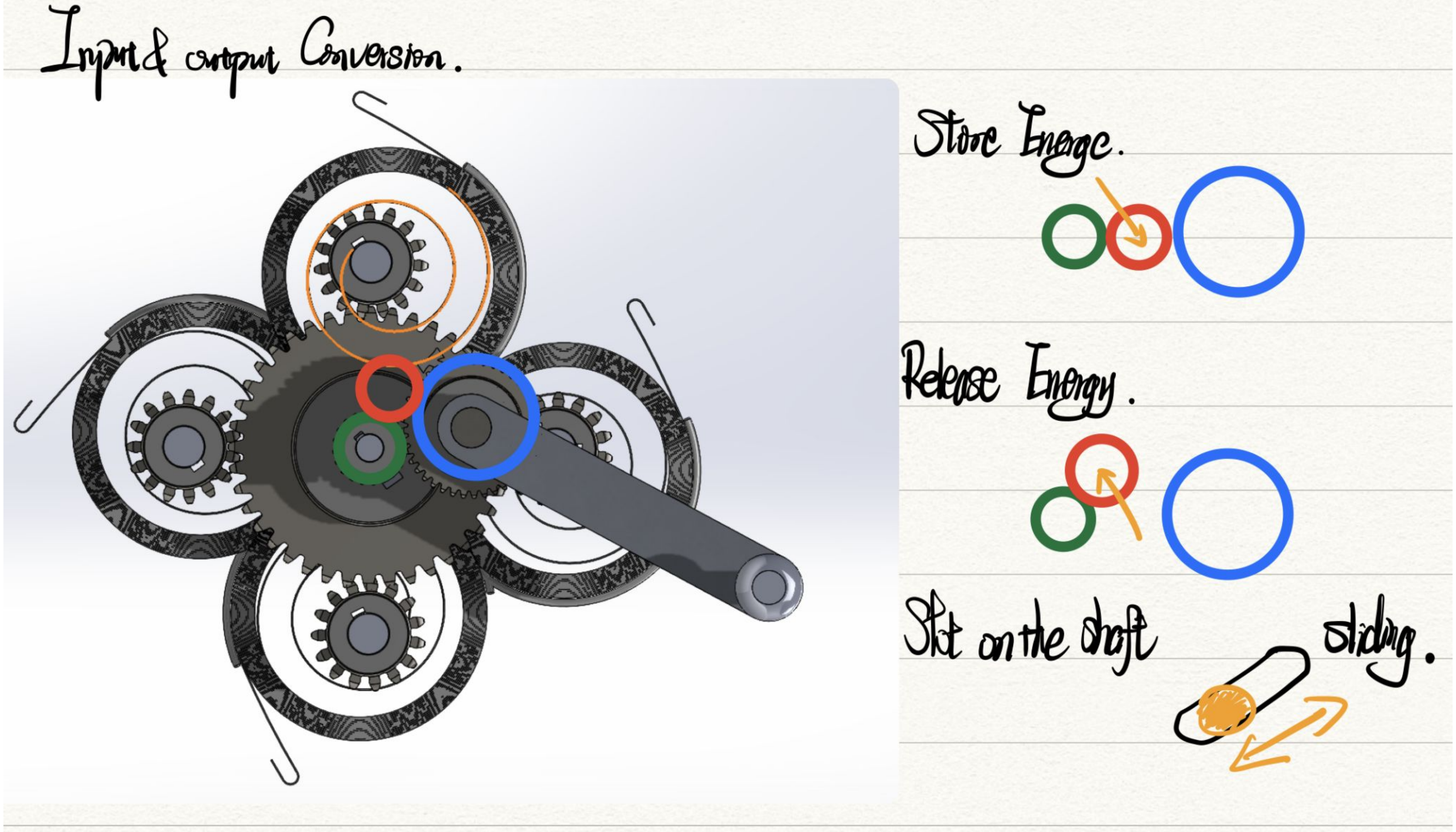
What steps did we take to make the device as realizable as possible?

1. Significantly reduce the spring required for the design.

2. We designed our what if-charger product to maximize stability while reducing the size as much as possible.

3. The Key design is that we introduce a moveable gear between the small gear on top of the main shaft and the large gear right behind the hand-crank structure.

Feasibility



Feasibility

State whether the client's idea is feasible and provide reasons as to why or why not?

1. The size of the box contain gears and springs is 120*120*35mm and the box for hand-crank is 75*50*20mm. The overall size is about 200*200*170mm, which is a little large.

2. The weight of the product is about

3. The product is a little bit expensive. We can use cheaper gears to lower the cost.

4. The force applied on the hand-crank need to be larger than 500N. It's more efficient to do the input with human feet, probably this product can be installed on a foot fitness machine.

Reference

[1]. Coldadler. “Torsion Spring Reaction Force.” *Physics Forums | Science Articles, Homework Help, Discussion*, Physics Forums, 1 Mar. 2020, https://www.physicsforums.com/threads/torsion-spring-reaction-force.984929/.

[2]. Chen, Jen-San, and I-Shein Chen. “Deformation and Vibration of a Spiral Spring.” *International Journal of Solids and Structures*, Pergamon, 11 Apr. 2015, https://www.sciencedirect.com/science/article/pii/S0020768315001377.