University of Nottingham
UK | CHINA | MALAYSIA

Individual Gearbox Actuator

Preparations for PDR

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What should be included in PDR submission?

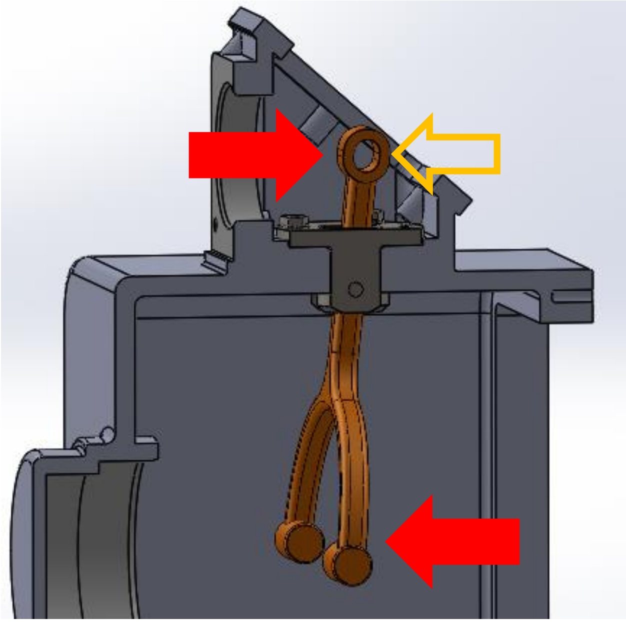
- **A single report in PDF format submitted on Moodle by 3pm, Friday, 3rd March**
- **A PDR check list** and **PDR pro-forma** are available in the **Individual Gearbox Actuator) folder** in the **Design Tutorial and Support** section on Moodle
- **PDR report should include (in PDF format)**
  - ~~Completed PDR checklist (1 page from Pro forma)~~
  - Statement of Requirements (1 page from Pro forma)
  - Concept sketches with annotations (1 page)
  - Morphology chart (1 page from Pro forma)
  - Calculations (1~2 pages)
  - Concept selection (1 page)
  - Time management (1 page from student guideline Pro forma)
- **A typical PDR report is between 7~9 A4 pages**
- Use the name "Surname-Initials_ID number" in submission, e.g. "Student-A_20345678"

What are the key questions for consideration and solutions

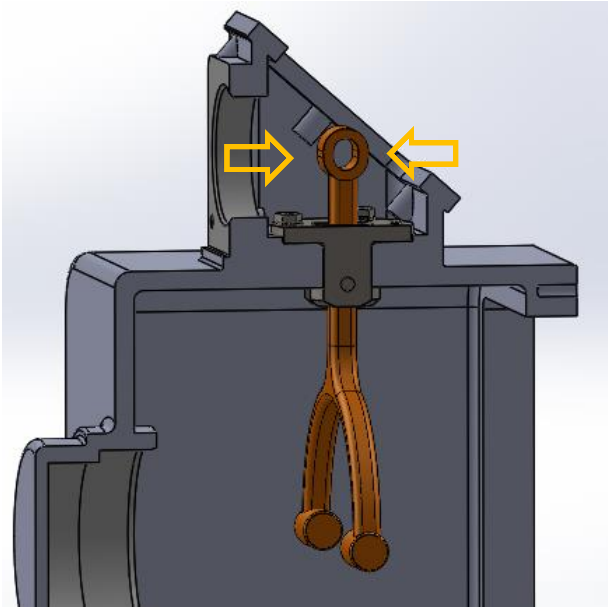
- **What are the key requirements of the design?**
  - Read carefully the MSG Meeting note in project brief.
- **How to capture key functional and performance requirements of the Actuator?**
  - A clear and concise statement of requirements using the pro-forma
- **How to think of possible means to meet enabling functions?**
  - Use Morphology chart pro-forma to map out all possible options and make sure the optimum solution meets all requirements and is practical to operate
- **What is exactly to be designed and what is NOT part of the task?**
  - Only the actuator including the bit for failure mode BUT NO Control/Valve, etc
- **What are the needed calculations for PDR submission?**
  - Power and torque for the gearbox and force calculation of the Hirth Clutch and how these can be used in concept design/selection of the Actuator
- **How to select the best possible solution?**
  - Effective use of the decision matrix method plus justification for your decision
- **How to assess the efficiency and productivity of your work for PDR?**
  - Estimation of the time you spent and discuss ways for improvement

Gearbox actuator operation

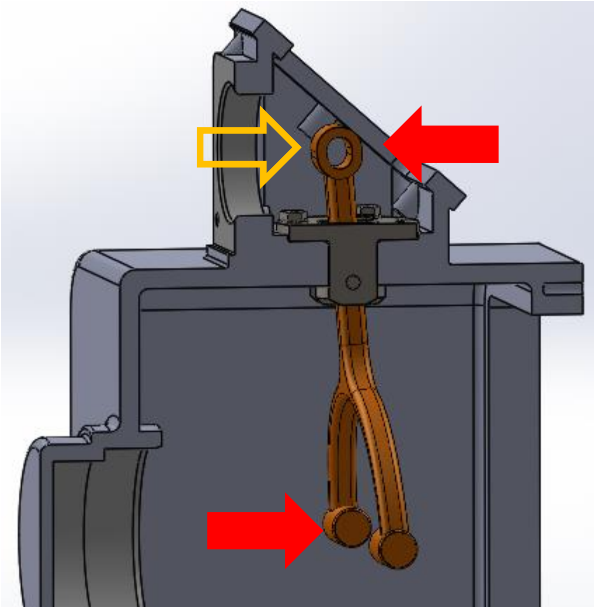
- **Actuation to achieve three positions**



Actuation force to
Z=2:1 gear ratio



Initial load in
Neutral position

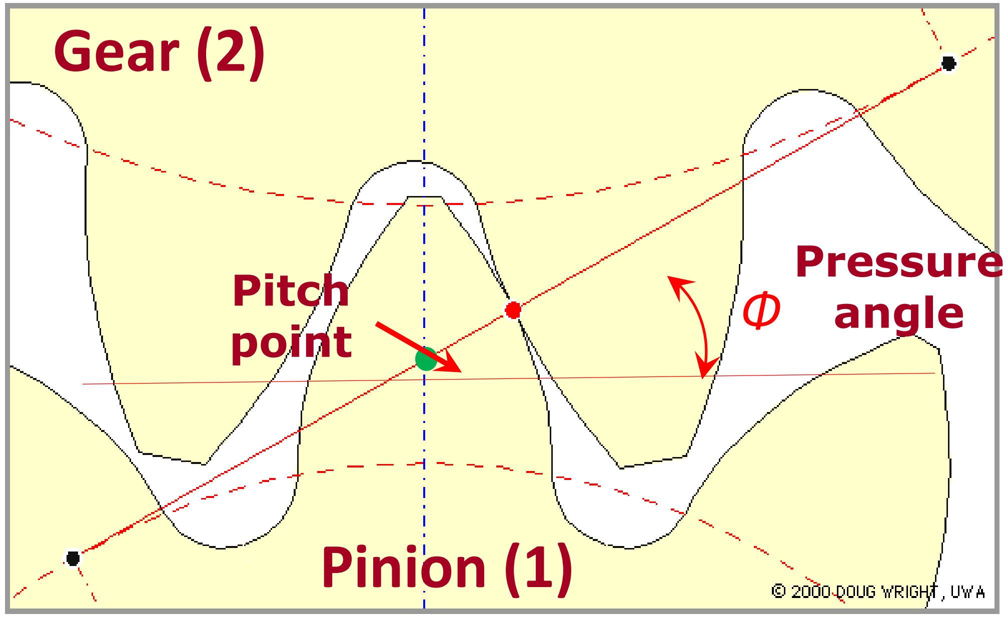


Actuation force to
Z=1:1 gear ratio

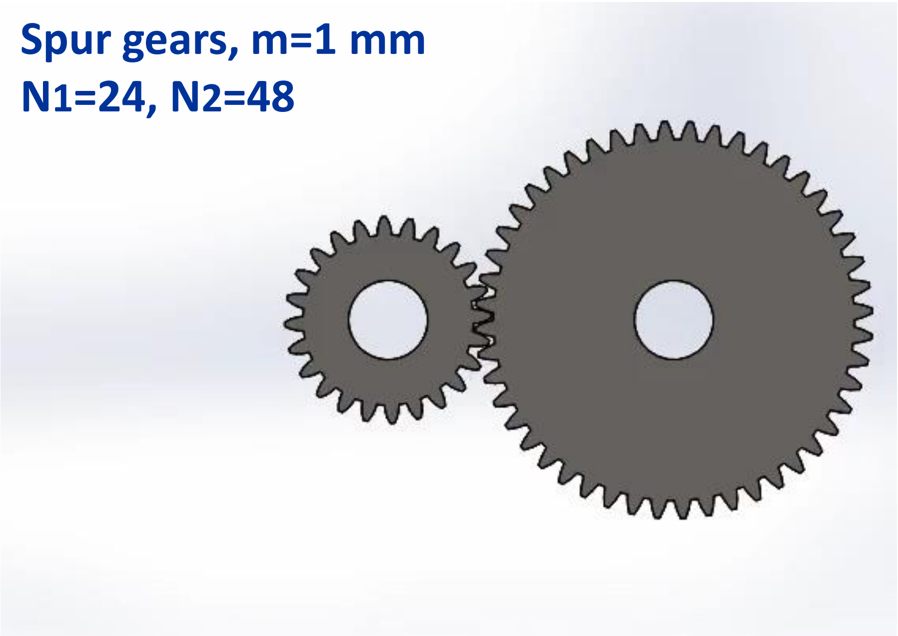
How to calculate these actuation forces and what's actuation displacement?

Recap of Gears 1

Gears are the most rugged, durable and efficient means of power transmission between two shafts.



http://www.mech.uwa.edu.au/DANotes/gears/meshing/meshing.html



Details to refer **Gears 1 Lecture slides and Handouts** available on Moodle

Gear ratio equation: $$Z = \frac{\omega_1}{\omega_2} = \frac{d_2}{d_1} = \frac{N_2}{N_1}$$

Necessary & sufficient conditions :

$$m_1 = m_2, \quad \phi_1 = \phi_2$$

Note: The most commonly used pressure angle is **ϕ** or **α** = 20^0

Pitch diameter: d=mN,

m is Module, *in mm (SI unit)*

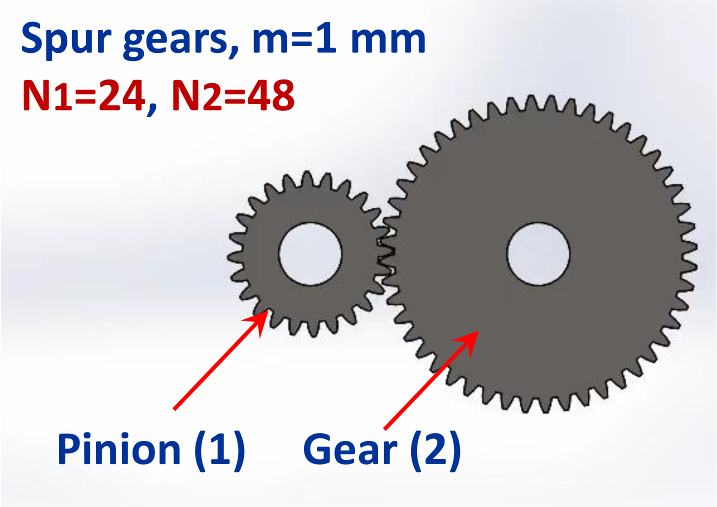
N is number of teeth

An example: Power & torque calculation of a gear train

- **Power equation of a rotating system** (as of the air motor)

$$P = T \times \omega \qquad \& \qquad \omega = \frac{2\pi}{60} n$$

where, P is power (W),
T is torque (Nm),
ω is rotating speed (rad/s),
n is rotating speed (rpm).



For the simple gear train shown, the power input is ***P = 50 W*** from **pinion (1)** at ***n_1 = 200 rpm***. Calculate the rotating speed and torque output from **gear (2)**.

Note: Spur gears are highly efficient so **power loss can be neglected in calculation**.

1) Use gear ratio equation: $Z = \frac{\omega_1}{\omega_2} = \left(\frac{n_1}{n_2}\right) = \frac{N_2}{N_1}$ $\qquad n_2 = \frac{N_1}{N_2} \times n_1 = \frac{24}{48} \times 200 = 100\ (rpm)$

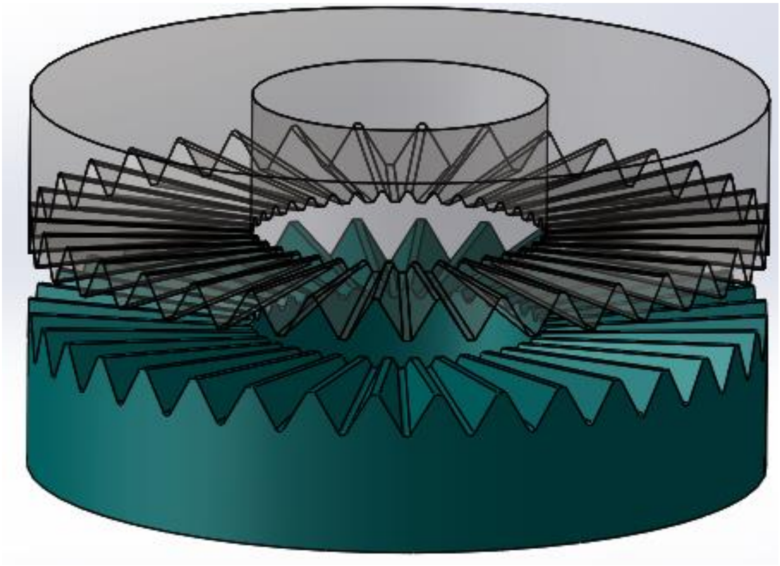
2) Use power equation:

$$T_2 = \frac{P}{\omega_2} = \frac{P}{n_2} \times \frac{60}{2\pi} = \frac{50}{100} \times \frac{60}{2\pi} = 4.8\ (Nm)$$

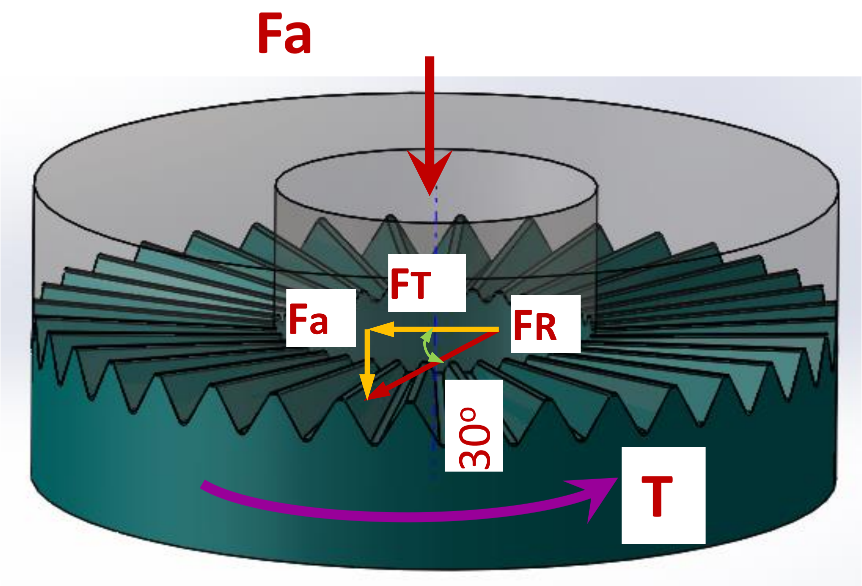
Can you calculate torque & speed of the 2-speed gearbox at given operation condition?

Hirth clutch forces and torque

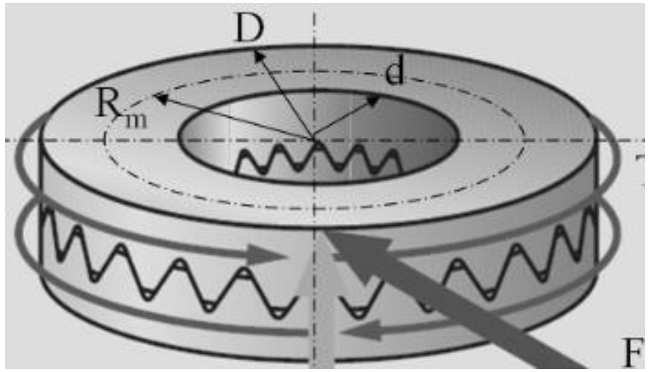
- **Hirth clutch axial, tangential forces and torque**



Disengaged



Engaged



$$F_a = kF_T tan\left(\frac{\pi}{6}\right)$$

$$F_T = \frac{T}{R_m}$$

where,

k=1.5 – coefficient

Fa, FT – axial, tangential forces

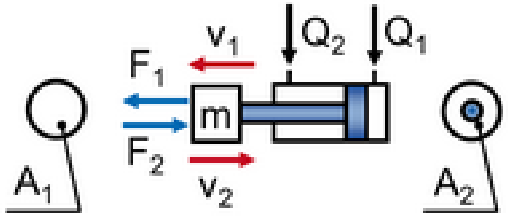
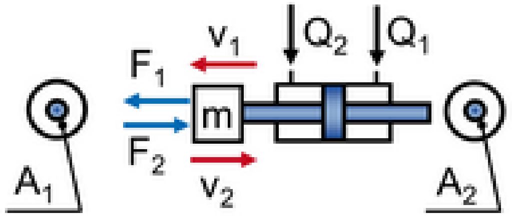
T – torque

Rm – medium radius of Hirth coupling

Basic sizing of hydraulic actuators

- **Key factors for consideration in designing hydraulic actuators**
  - Working conditions: pressure, force, stroke distance, speed, temperature
  - Cylinder bore and piston rod sizes
  - Methods for sealing
  - Mounting style/interface

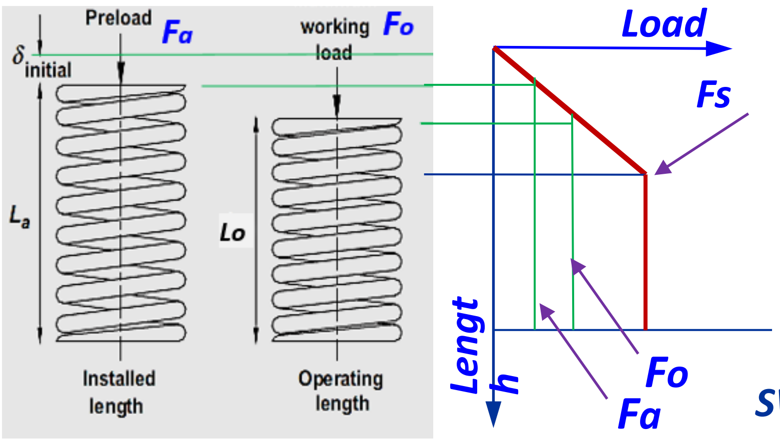
D_k	Bore
d_s	Piston rod diameter
p	Pressure in cylinder
A_1, A_2	Working areas of cylinder
F_1, F_2	Force extending and force retracting of cylinder

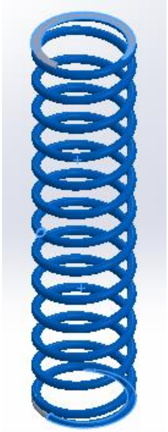
Calculation formulae	Single-rod cylinder $A_2 < A_1$	Double-rod cylinder $A_2 = A_1$
		
Working ares for extension	$A_1 = \frac{\pi}{4} \bullet D_k^2$	$A_1 = \frac{\pi}{4} \bullet (D_k^2 - d_s^2)$
Working area for retracting	$A_2 = \frac{\pi}{4} \bullet (D_k^2 - d_s^2)$	$A_2 = \frac{\pi}{4} \bullet (D_k^2 - d_s^2)$
Power when extending	$F_1 = p \bullet A_1$	
Power when retracting	$F_2 = p \bullet A_2$	

https://www.haenchen-hydraulic.com/technical-information/hydraulic-cylinder/calculation.html

A worked example: Selection of compression spring from a spring supplier (LeeSpring)

➢ Select a compression spring required to exert a force of **35 N** when compressed to a length of **60 mm**. At a length of **48 mm**, the force must be **50 N**. The spring is to be installed in a **hole with 24 mm diameter**.





SW model download from LeeSpring®

From the above, we know

Fa = 35 N, La = 60 mm & Fo = 50 N, Lo = 48 mm

From slide 9,

$$k = \frac{F_o - F_a}{L_a - L_o} = \frac{50 - 35}{60 - 48} = 1.25\ (N/mm)$$

$$L_f = 60 + \frac{35}{1.25} = 88\ (mm)$$

Check Lee Spring® catalogue at https://www.leespring.co.uk/

Can you select a compression spring for a mountain bike?

Lee Spring® | About Us | Stock Parts | Request a Quote | Request a Catalogue | Resource Center | Contact Us

○ Imperial/Inches ◉ Metric

Physical Dimension ◉ mm ○ cm

Load ◉ N ○ kg ○ gm

Reset All

Filter

Outside Diameter

Part Number	Outside Diameter (mm)	Hole Diameter (mm)	Rod Diameter (mm)	Free Length (mm)	Rate (N/mm)	Solid Height (mm)	Wire Diameter (mm)	Material	Compare
LC 050K 09 S316	21.46	22.23	18.19	88.9	0.368	12.34	1.27	SS316	☐
LC 085K 10 S316	21.46	22.23	16.61	88.9	2.189	30.23	2.16	SS316	☐
LC 075K 11 M	21.46	22.23	17.12	88.9	1.53	27.27	1.91	MW	☐
LC 055K 09 S	21.46	22.23	17.98	88.9	0.49	14.45	1.4	SS	☐
LC 075K 11 S316	21.46	22.23	17.12	88.9	1.275	27.27	1.91	SS316	☐
LC 091K 08 S	21.46	22.23	16.31	88.9	2.845	33.07	2.31	SS	☐

A worked example: Selection of disc spring

- Select **Spirol disc springs** required to exert an initial force of **200 N** at ***0.15ho*** and a maximum operational force of **700 N** under further **2.7 mm** deflection. The spring is to be installed in a **hole with 24 mm diameter**.

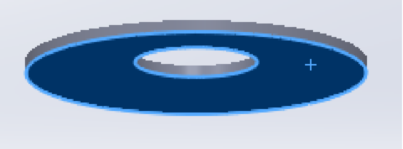
From the above, we know

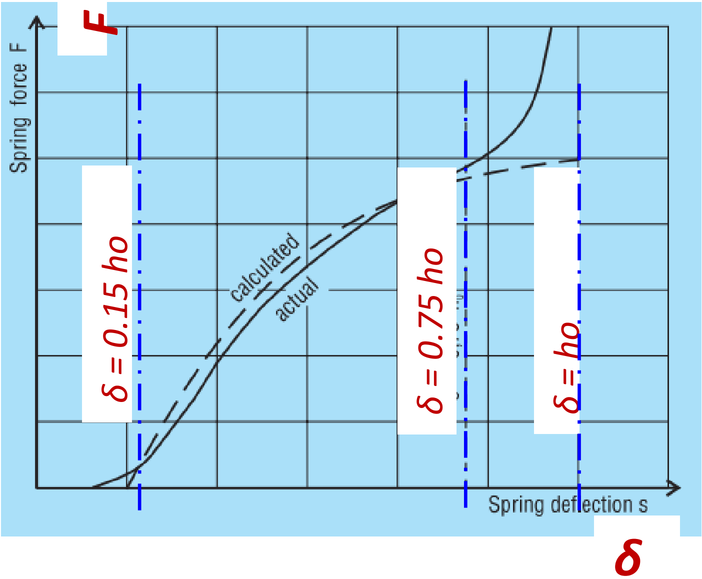
$$s1 = 0.15ho \rightarrow Fa1 = 200\ N\ \&\ s2 = 0.75ho \rightarrow Fa2 = 700\ N$$

From Spirol disc spring table,

$$s1 = 0.15ho = 0.11\ mm\ \rightarrow Fa1 = 214\ N$$

$$s2 = 0.75ho = 0.56\ mm\ \rightarrow Fa2 = 719\ N$$





$\Delta s = S2 - S1 = 0.6ho$ =0.45 (mm) → N=S/ Δs =2.7/0.45 = 6 (springs)

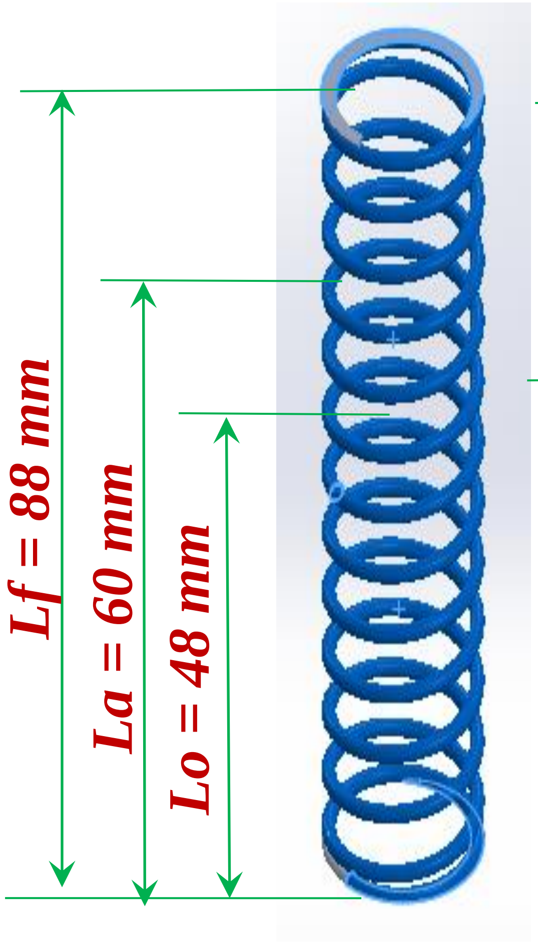
SW model download from LeeSpring®

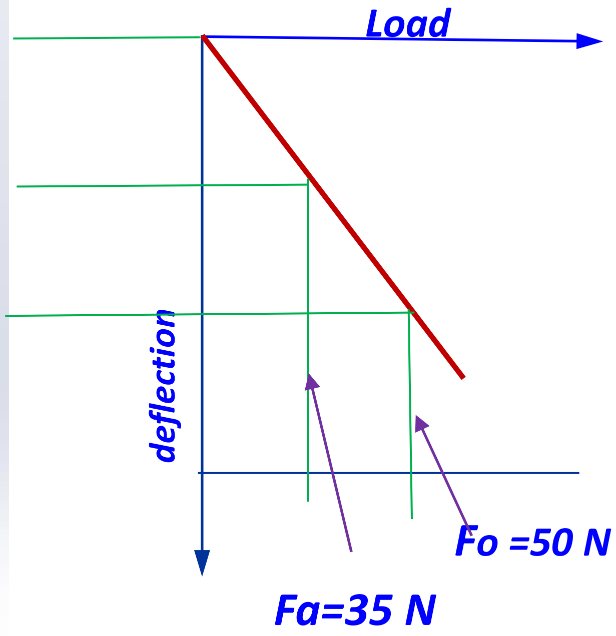
DISC SPRINGS TO DIN EN 16983 (formerly DIN 2093)

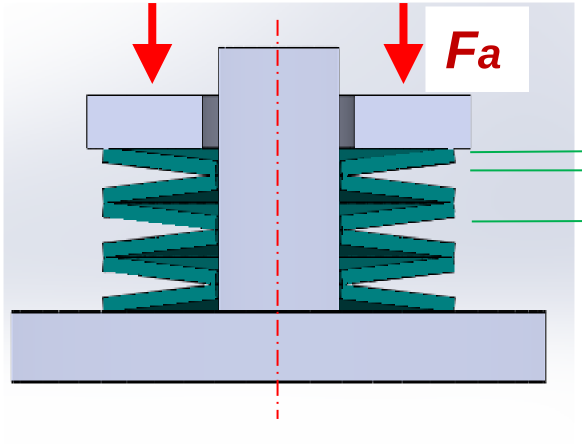
DIN Series	Dimensions						Design Force, Deflection and Stresses Based on E = 206 kMPa and μ = 0.3																							
							Preload, $s = 0.15\ h_o$					$s = 0.25\ h_o$					$s = 0.5\ h_o$					$s = 0.75\ h_o$					$s = h_o$		
	D_e	D_i	t	l_o	h_o	h_o/t	s	l_t	F	σ_{II}	σ_{III}	s	l_t	F	σ_{II}	σ_{III}	s	l_t	F	σ_{II}	σ_{III}	s	l_t	F	σ_{II}	σ_{III}	s	F	σ_{OM}
C	22.5	11.2	0.60	1.40	0.80	1.33	0.12	1.28	160	-23	302	0.20	1.20	240	-14	488	0.40	1.00	370	98	897	0.60	0.80	426	336	1,227	0.80	444	-1,178
B	22.5	11.2	0.80	1.45	0.65	0.81	0.10	1.35	195	93	253	0.16	1.29	306	171	412	0.33	1.13	533	425	771	0.49	0.96	707	762	1,079	0.65	855	-1,276
A	22.5	11.2	1.25	1.75	0.50	0.40	0.08	1.68	424	224	234	0.13	1.63	693	383	384	0.25	1.50	1,330	815	737	0.38	1.37	1,929	1,296	1,059	0.50	2,509	-1,534
	23.0	8.2	0.70	1.50	0.80	1.14	0.12	1.38	[illegible]	37	245	0.20	1.30	279	87	397	0.40	1.10	448	295	733	[illegible]	0.90	[illegible]	626	1,007	0.80	602	-1,173
	23.0	8.2	0.80	1.55	0.75	[illegible]	0.11	1.44	214	92	237	0.19	1.36	332	175	384	0.38	1.18	560	457	714	0.56	0.99	719	846	991	0.75	842	-1,257
	23.0	8.2	0.90	1.70	0.80	0.89	0.12	1.58	311	125	277	0.20	1.50	486	233	449	0.40	1.30	829	589	837	0.60	1.10	1,078	1,066	1,164	0.80	1,279	-1,508

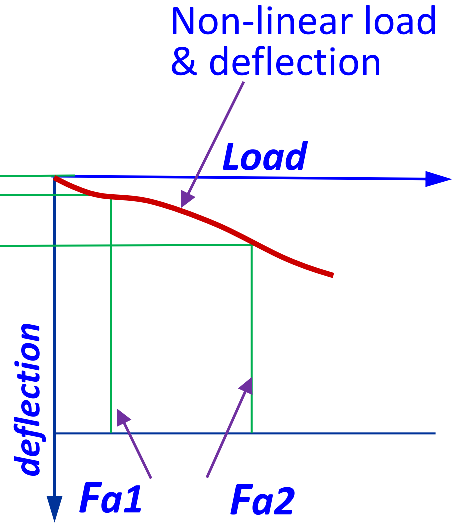
Recap of selection of coil and disc springs

- **Coil compression spring** vs **disc spring**









$$s1 = 0.15ho = 0.11\,mm \;\rightarrow Fa1 = 214\,N$$

$$s2 = 0.75ho = 0.56\,mm \;\rightarrow Fa2 = 719\,N$$

$$6 \times \Delta s = 6 \times 0.6ho = 6 \times 0.45 = 2.7\,mm$$

SW models of both the coil & disc springs are downloaded from LeeSpring website

- **Compression springs have a large deflection and spring rate range**
- **Disc springs require a large force to exert a small deflection**

Lf = 88 mm, Fa = 35 N, La = 60 mm & Fo = 50 N, Lo = 50 N