Lectures on mechanics

(LESSON #2)

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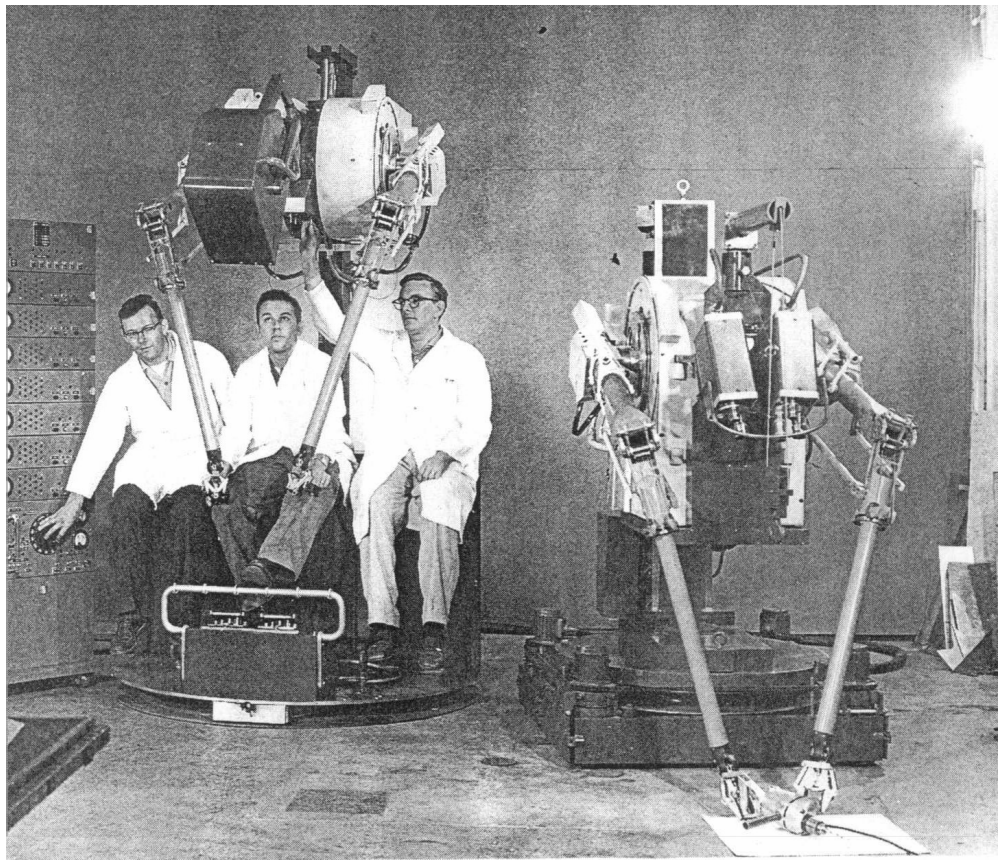


LESSONS TIME TABLE (pls. take note)

28/11 h9/12- mech components 1 (3h)
4/12 h9/12 mech components 2 (3h)
11/12 h9/12 mech technologies (3h)
16/12 h 9/12 (in TLR) - mech technologies tlr workshop
19/12 h9/12- robotic (3h) CHANGED!!

STUDENT LIST

Baizid Khelifa
Biso Maurizio
Iqbal Jamshed
Jafari Amir
Naceri Abdeldjallil
Palyart Lamarche Jean-Christophe
Patra Niranjan

HYDRAULIC AND PNEUMATIC ACTUATION
(fast discussion)

CYLINDERS
generally directly connected to the load

MOTORS
may be direct or connected to the load with a gearbox

HYDRAULIC AND PNEUMATIC CONTROL

The following values can be controlled indipendently:

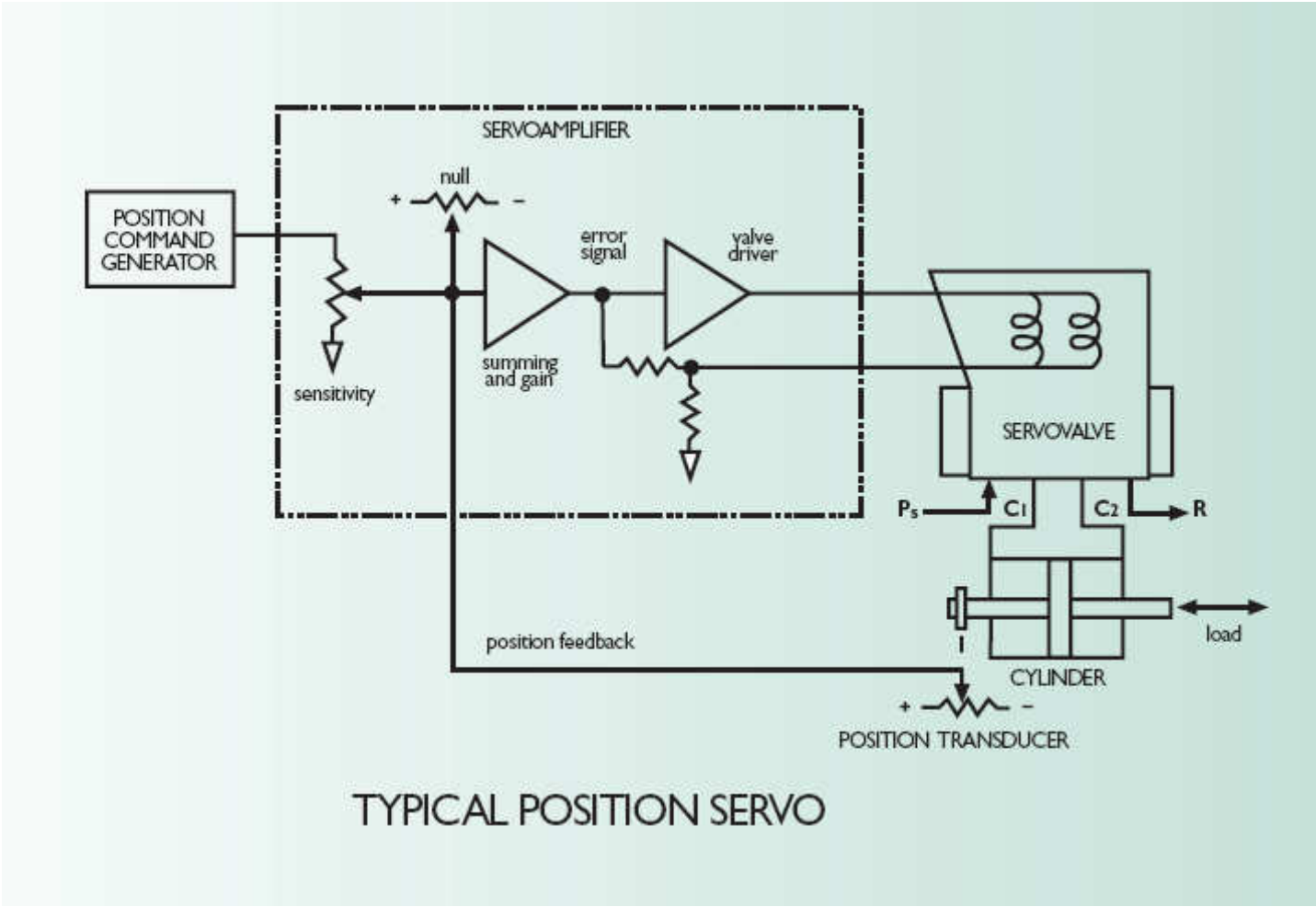
* **POSITION;**
* **SPEED;**
* **FORCE**

As a frist approximation the following relations can be defined:

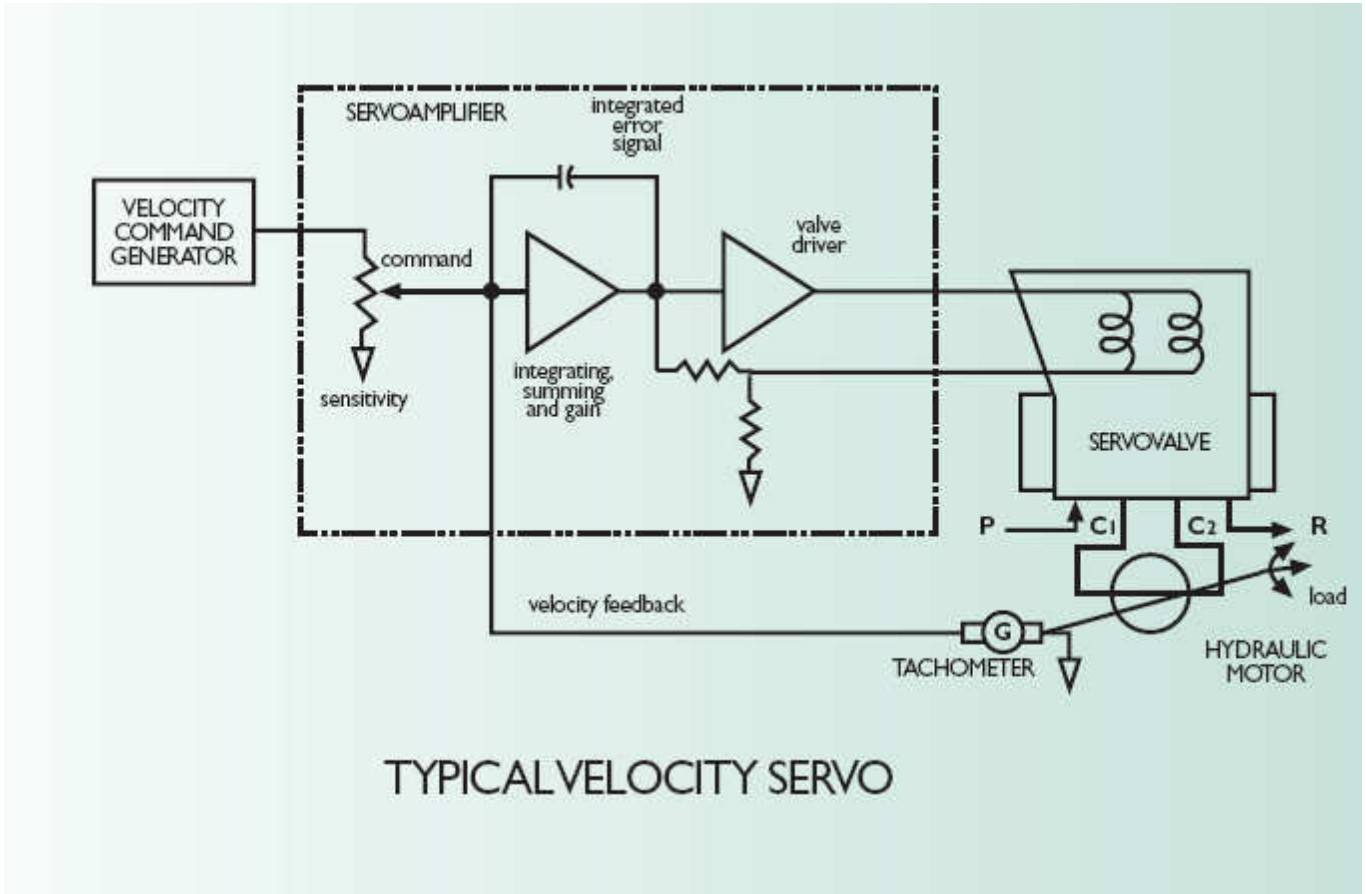
* **SPEED -> FLOW;**
* **POSITION -> FLOW OVER TIME;**
* **FORCE -> PRESSURE**

EACH VALUE CAN BE CONTROLLED WITH..

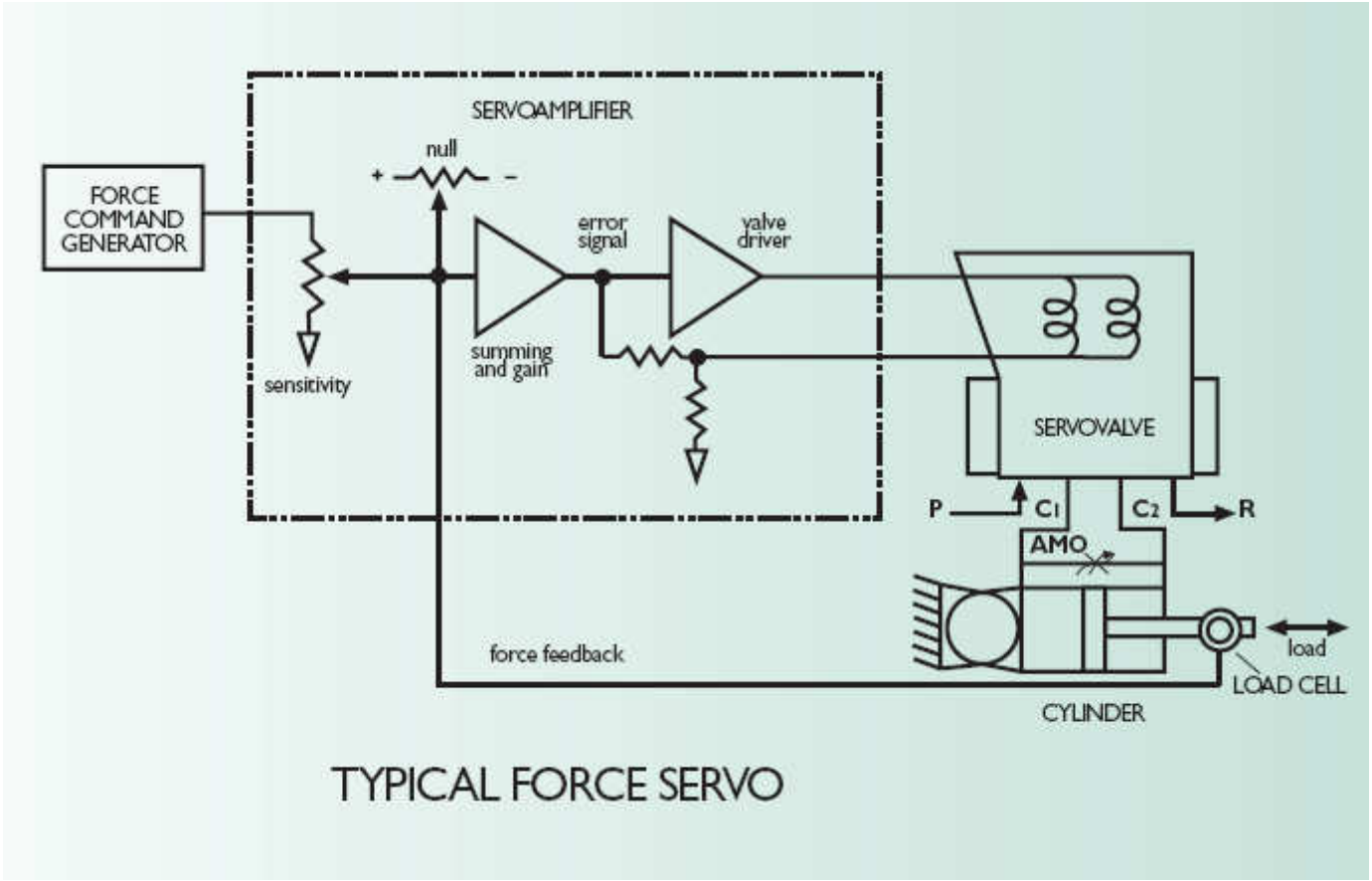
Generally control valve are on/off but "proportional" control il possible with different feedback options..



TYPICAL POSITION SERVO



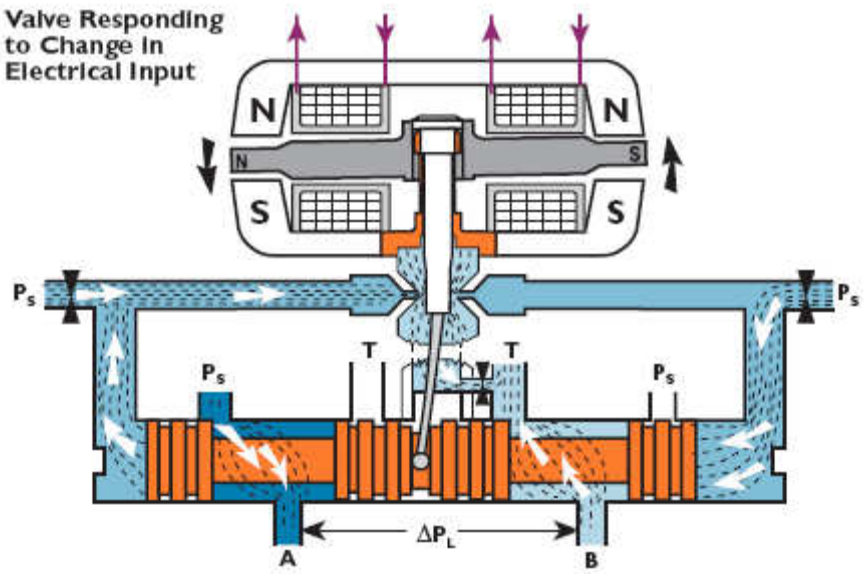
TYPICAL VELOCITY SERVO

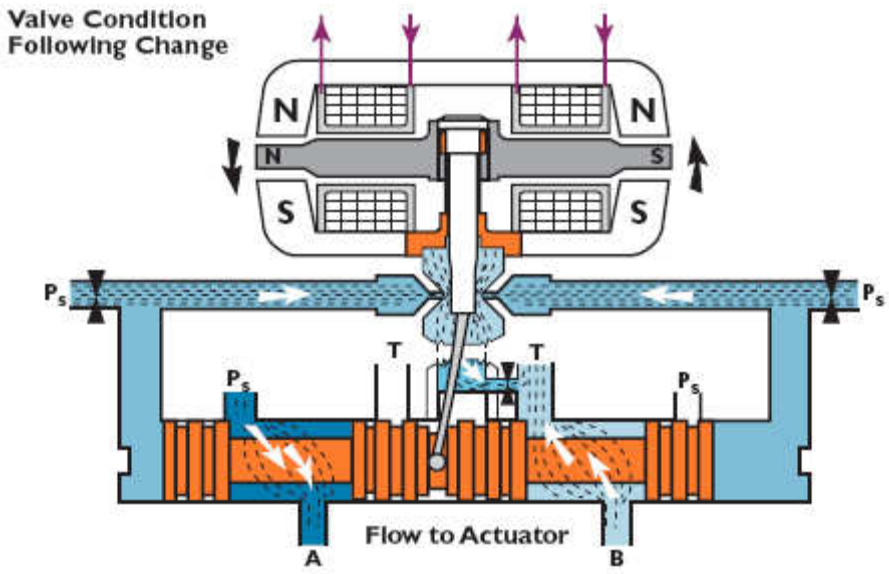


TYPICAL FORCE SERVO

HYDRAULIC PROPORTIONAL VALVES

mechanical feedback between solenoid and valve spool

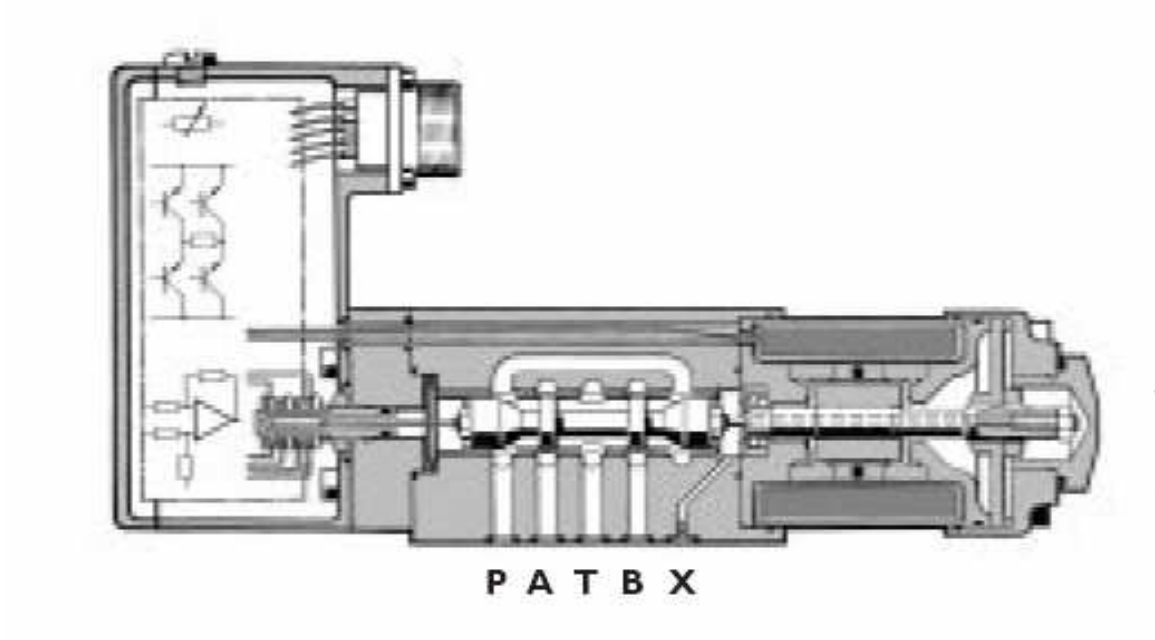


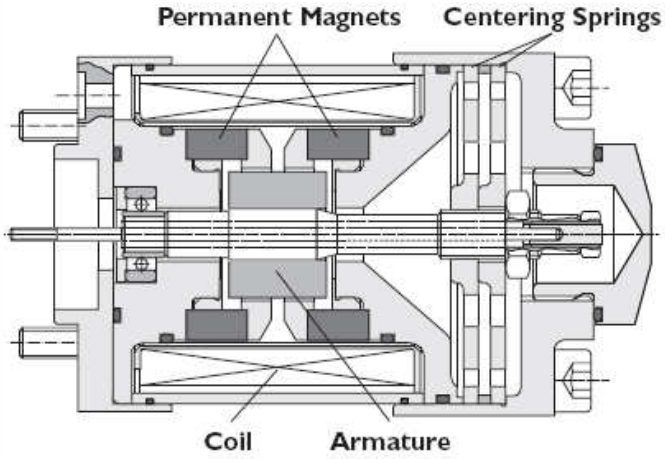


Ps: supply line (form hydraulic power unit);
T: return line (to hpu)
A,B: valve output to cylinder

HYDRAULIC SERVO VALVE

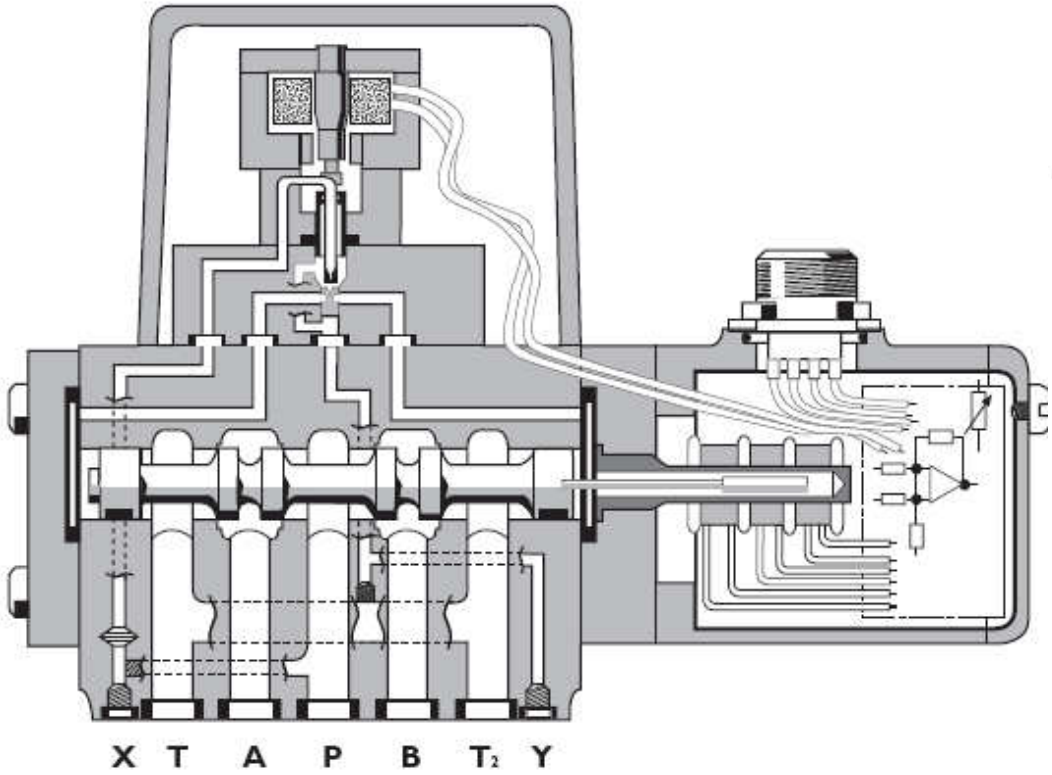
linear solenoid and linear sensor in line with the spool

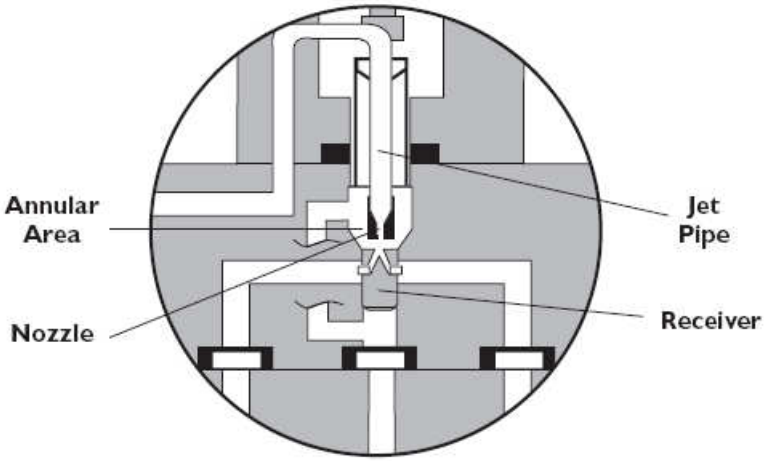




"SERVOJET" VALVES

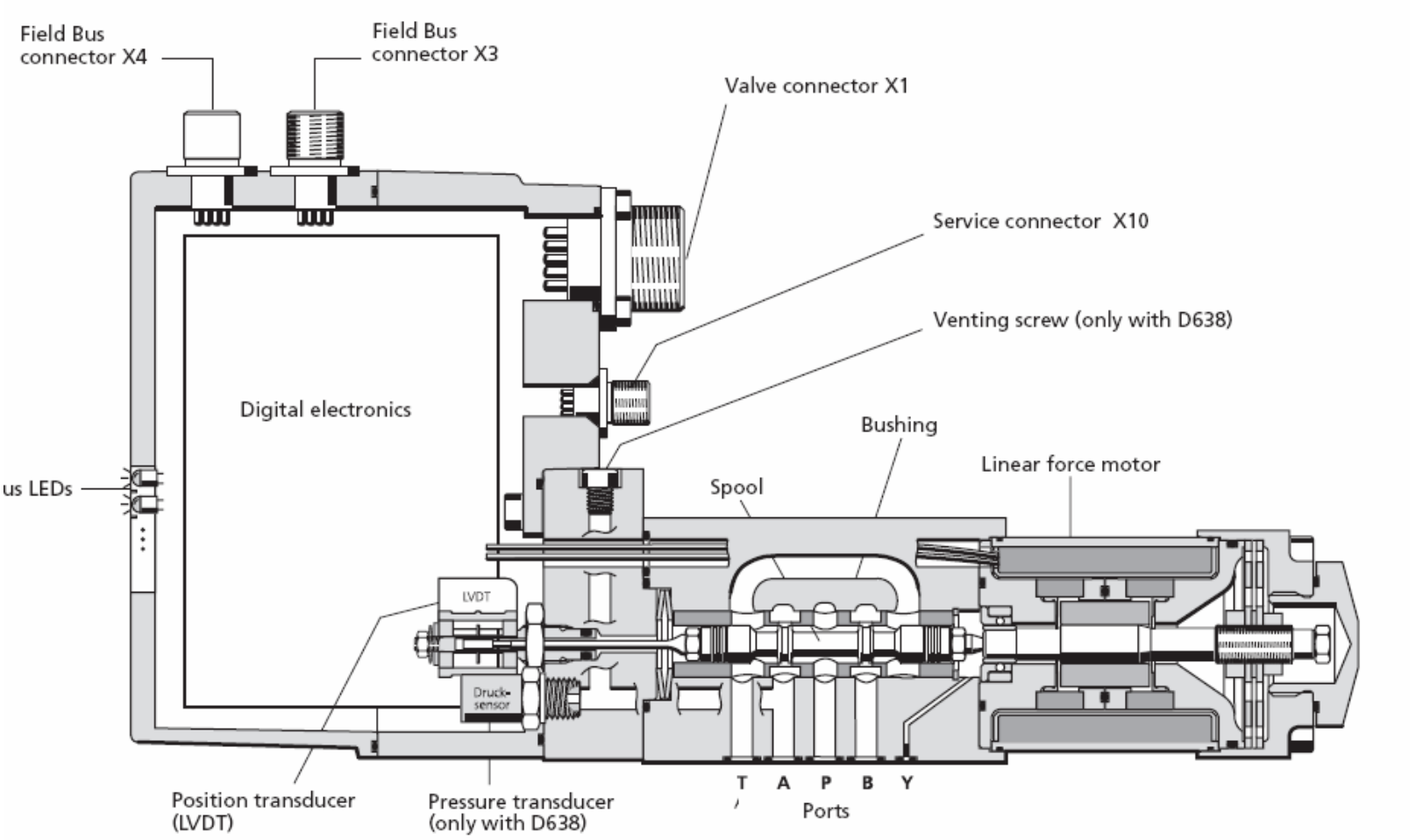
electrical feedback between solenoid and valve spool





pressure control servo valve

added pressure transducer on A output



POWER TRANSMISSION

Motion conversion

MOTION CONVERSION

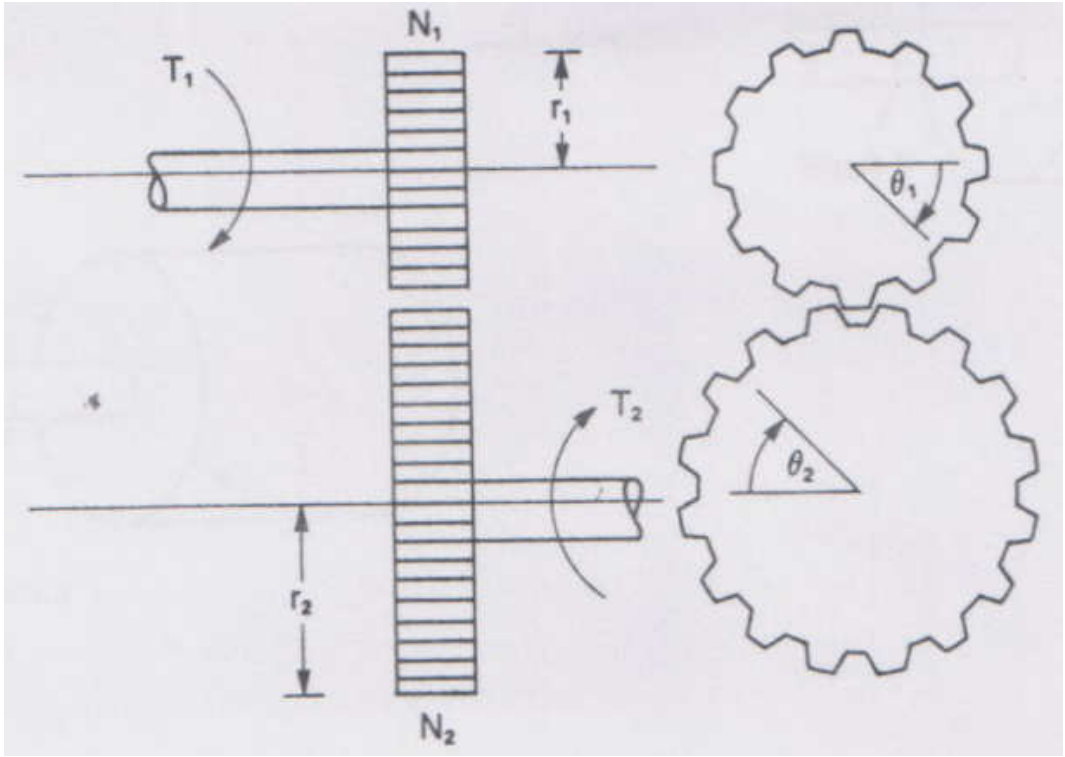
Components used to implement a practical joint usually consist of an actuator (motor) coupled to the physical joint by a **mechanical transmission**

This transmission is used to :

- change of rotational direction
- change of axis
- torque multiplication (or reduction)
- speed reduction (or multiplication)

IDEAL GEARS

By the ideal gear train we mean a transmission composed of gears that are perfectly round, rotate on their true centers and are also intertialess; the surface between the gears is also frictionless thereby creating no losses



Since the spacing between the teeth on each gear must be the same so that they mesh properly, the number of teeth on each gear is proportional to the radius of the gear.

Thus:

$$N_1/r_1 = N_2/r_2$$

The work done by the torque acting through an angular displacement on one shaft is equal to the torque acting through the corresponding angular displacement of the other shaft; then:

$$T_1\theta_1 = T_2\theta_2$$

The arc length of the distance traveled by one gear must equal that of the other that is, the distance traveled along the surface of each gear is the same

$$r_1\theta_1 = r_2\theta_2$$

Since the two gear radii do not vary with time, if the previous equations are differentiated with respect to time their relationship still holds but respect to $\dot{\theta}$ (angular velocity ω) or $\ddot{\theta}$ (angular acceleration α)

Using this concept we have:

$$N_1/N_2 = r_1/r_2 = T_1/T_2 = \theta_2/\theta_1 = \omega_2/\omega_1 = \alpha_2/\alpha_1$$

If the torque on shaft 1 is known, we can compute the torque on shaft 2 by:

$$T_2 = T_1 N_2/N_1$$

This particular relationship shows the speed reduction and torque moltiplication property of a gear train

A commonly used definition is that of **coupling ratio**: a coupling ratio of 2:1 means that two turn of the input shaft produce a single rotation of the output.

The **gear train** – like all kind of reduction gear boxes or equivalent systems (e.g. belt & pulleys) – is effective in reducing the reflected inertial and viscous loads that must be accelerated by a motor or any other actuator. So:

the actuator does not have to produce the high torque needed at the output

the actuator's torque capability can be signficantly smaller than that for direct appl.

In "real world" every transmission has an overall efficency.

The transmission efficency is the ratio between the input and the output power.

$$\eta_t = W_{out}/W_{in} = T_{out} / T_{in}$$

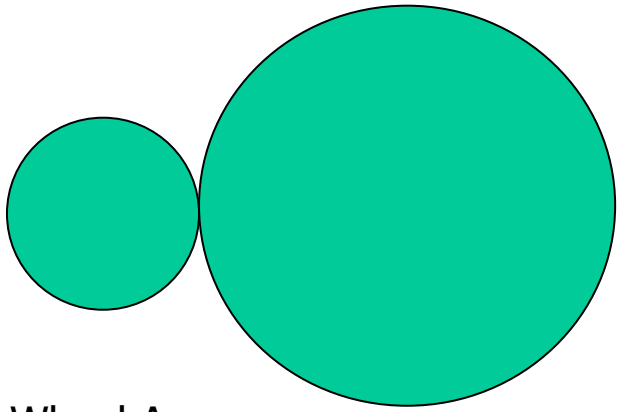
Practical considerations can place limits on gear type transmissions:

- Amount of torque vs teeth mechanical resistance
- Phisical size of gears (es. TR 1:100 -> output radius 100 times greater than the input) or multiple-pass gearing that increases the depth between input and output
- Opposite requirement i.e. need distance between input (actuator) and output

MOTION CONVERSION ROTARY TO ROTARY

- **Friction wheels**
- **Gear trains: spur, helical, bevel , worm**
- **Gearboxes: harmonic drive, epicyclic gears, cyclo**
- **Belt & pulleys**
- **Chain & spockets**

Friction wheels



Wheel A radius = rA
Wheel B radius = rB

Speed at contact point is the same for both the wheels

vA = wA*rA = wB*rB = vB

wA/wB = rB/rA

Trasmission ratio = rB/rA

Wheels must be radially loaded against each other. Slipping may occur if radial load is too low

ATTENTION:

Ftmax< Fn*(friction coefficient)

Hence:

Tamax=Ftmax*Ra

Tbmax=Ftmax*Rb

GEAR TRAIN

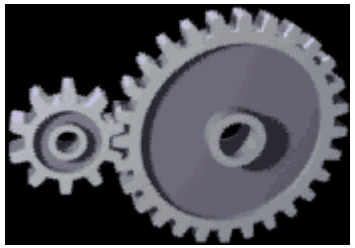
A gear is the coupling of two toothed wheels designed to transmit torque.

A couple of gears is called GEAR PAIR
generally several gear pairs are connected in series to increase the total reduction ratio
this is called GEAR TRAIN
each set of gears of the series is called STAGE

Spur gears

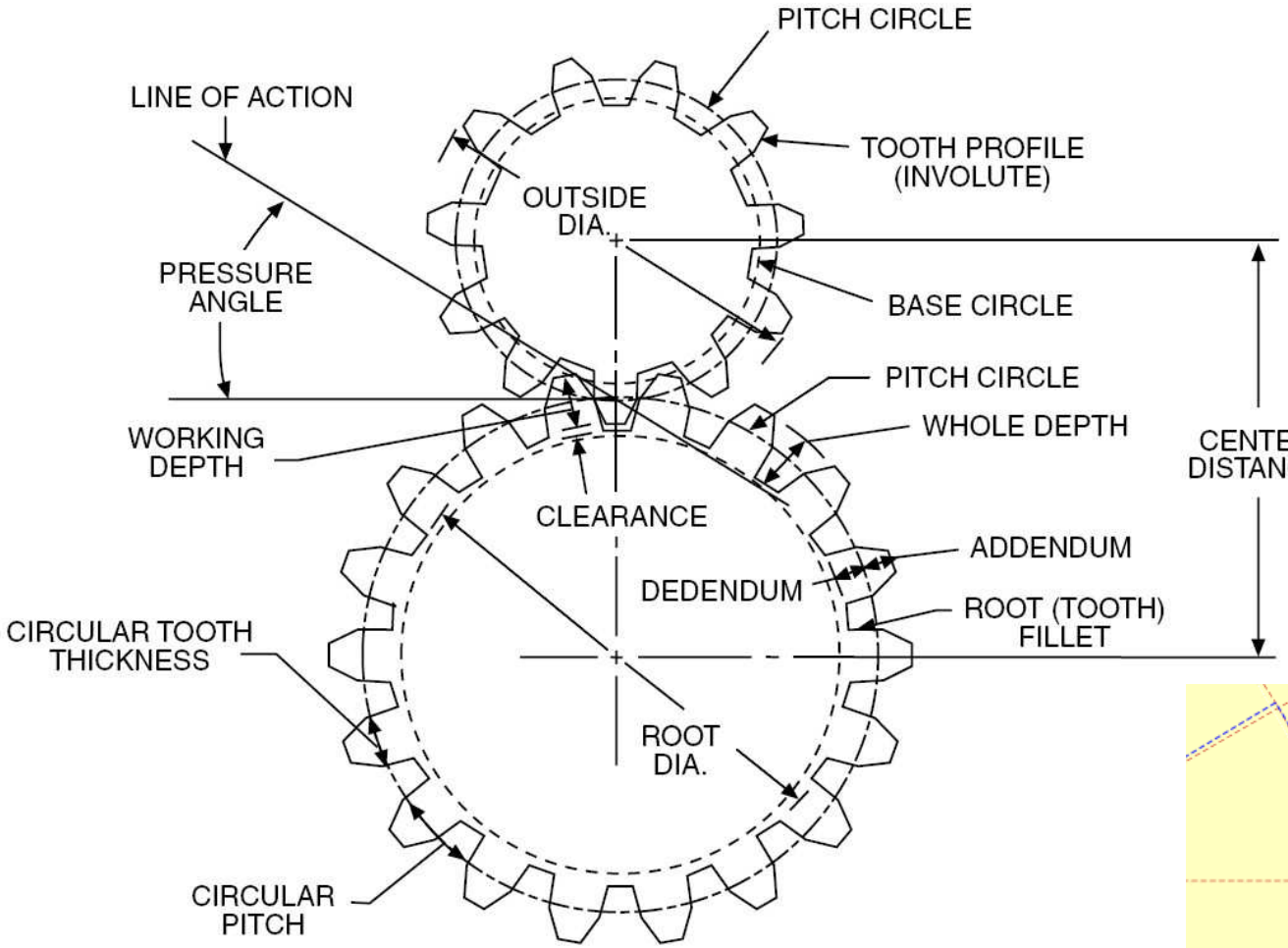
The most common type of gear wheel, spur gears, are flat and have teeth projecting radially and in the plane of the wheel.

The teeth of these "straight-cut gears" are cut so that the leading edges are parallel to the line of the axis of rotation. These gears can only mesh correctly if they are fitted to parallel axles.



Direction of contact forces

Spur gears

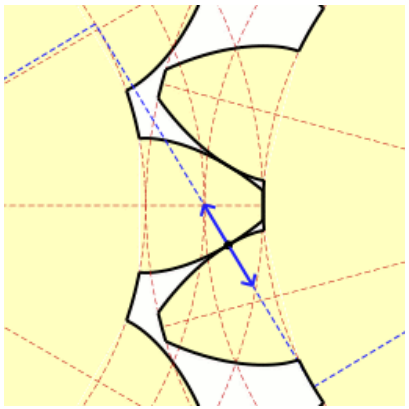


m = D/Z

D = pitch diameter

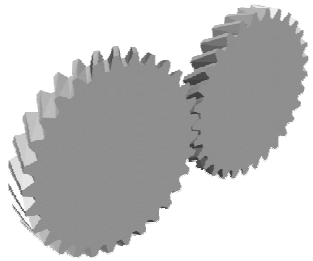
Z = number of teeth

m = modulus



Helical gears

Helical gears offer a refinement over spur gears. The teeth are cut at an angle, allowing for more gradual, hence smoother meshing between gear wheels.



PRO:

-Smoother meshing

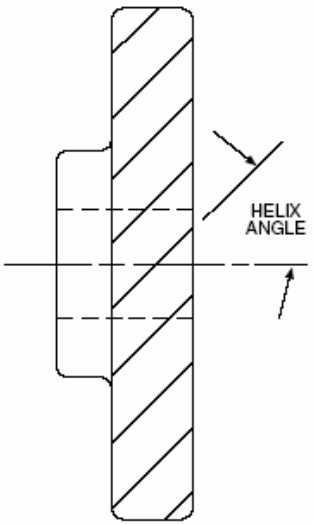
-Less noisy

-Higher torques transmitted

CONS:

-More difficult to machine

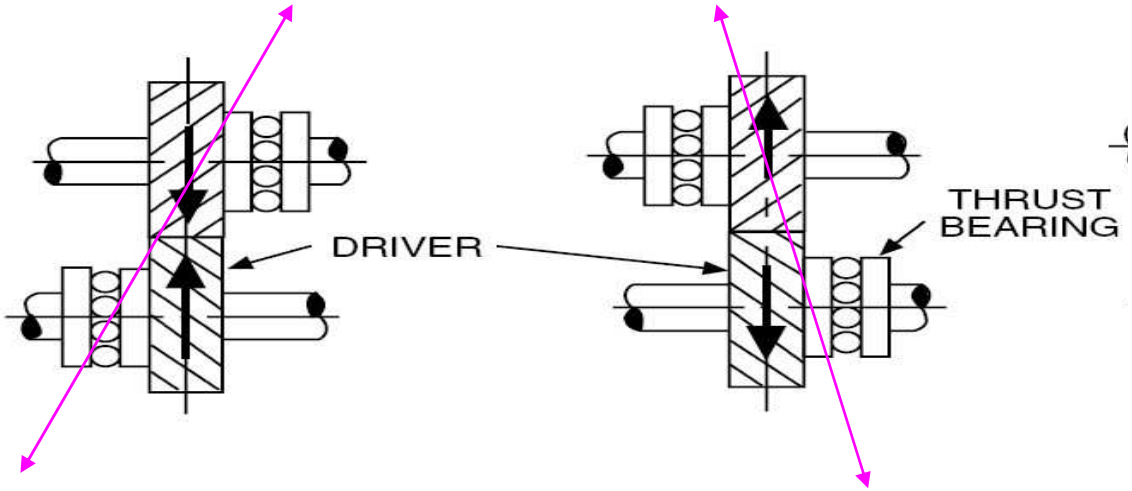
-Axial load



Small gear rotated in the picture!
(axis are parallel)

Helical gears

Effect of helix angle on gear design



direction of contact forces

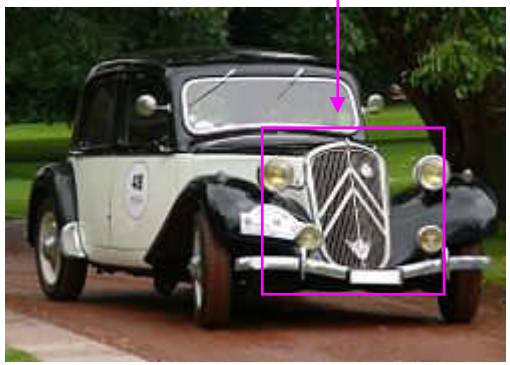
direction of contact forces

Double helical gears

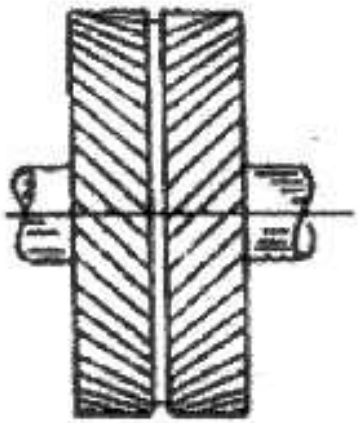
First used by Citroen, double helical gears neutralize the effects of axial thrust.

Two opposite helical gears are coupled to form a single wheel whose resultant axial thrust is null

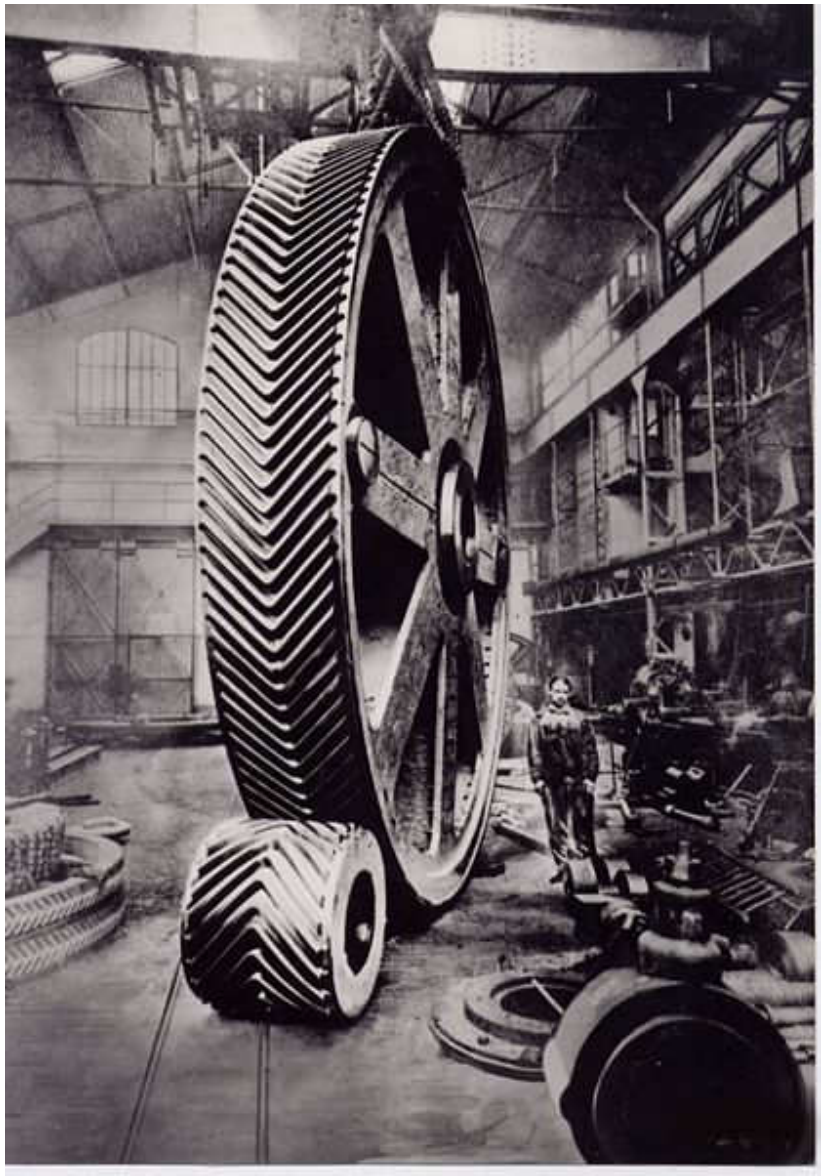
(..look at citroen brand..)



CITROËN

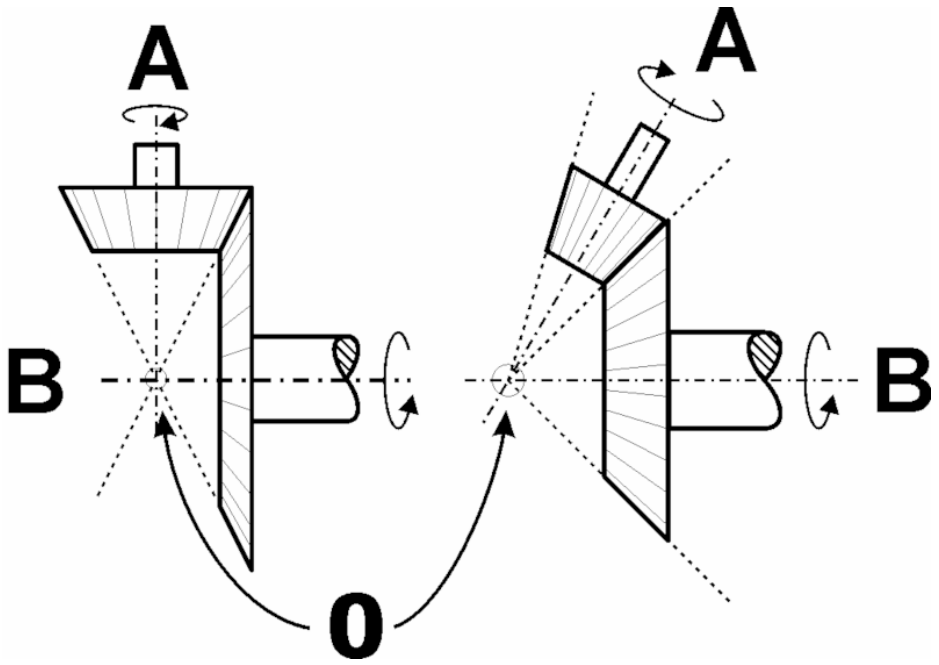


Double-Crossed Helical Gear



Bevel gears

Bevel gear is a conically shaped gear that allows for various angle between the wheels. The axes of the wheels must cross each other in a point



PROS:

-Operating angle can be different

CONS:

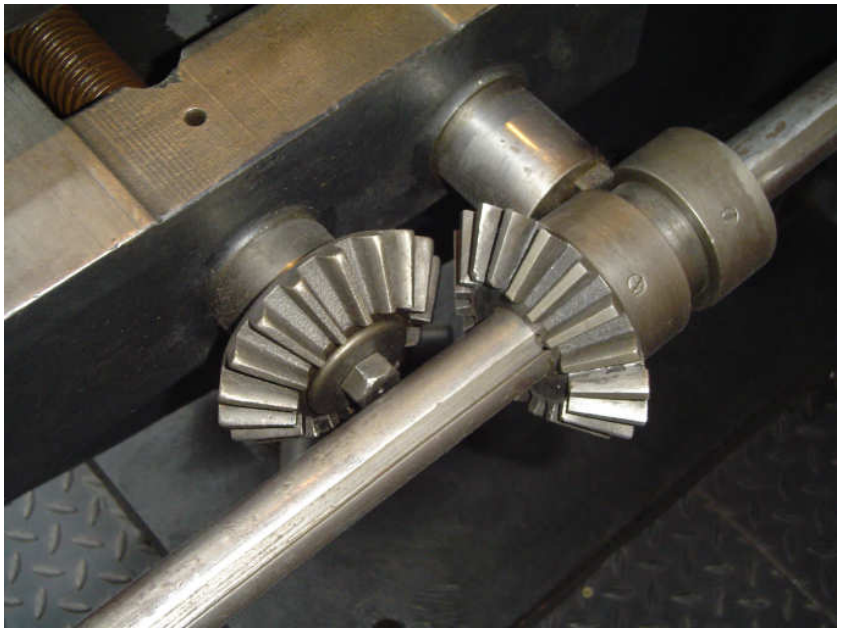
-One wheel of such gear is designed to work with it's complementary wheel and no other

-Must be rather precisely mounted

-The axes must be capable to support significant forces

Bevel gear teeth can also be helical shaped

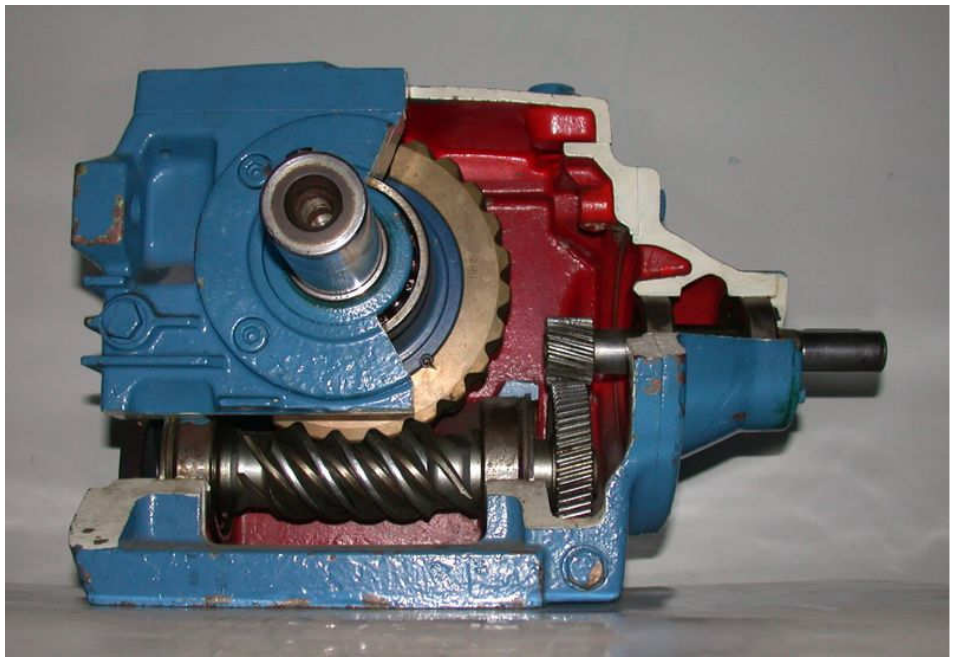
Conical pair (straight)



Conical pair (hypoid)

Worm gears

A worm gear is a gear in which a wheel resembles a screw, with parallel helical teeth, while the other is like a normal spur wheel. The worm gear can achieve a higher gear ratio than spur gears of a comparable size.



PROS:

-High transmission ratio

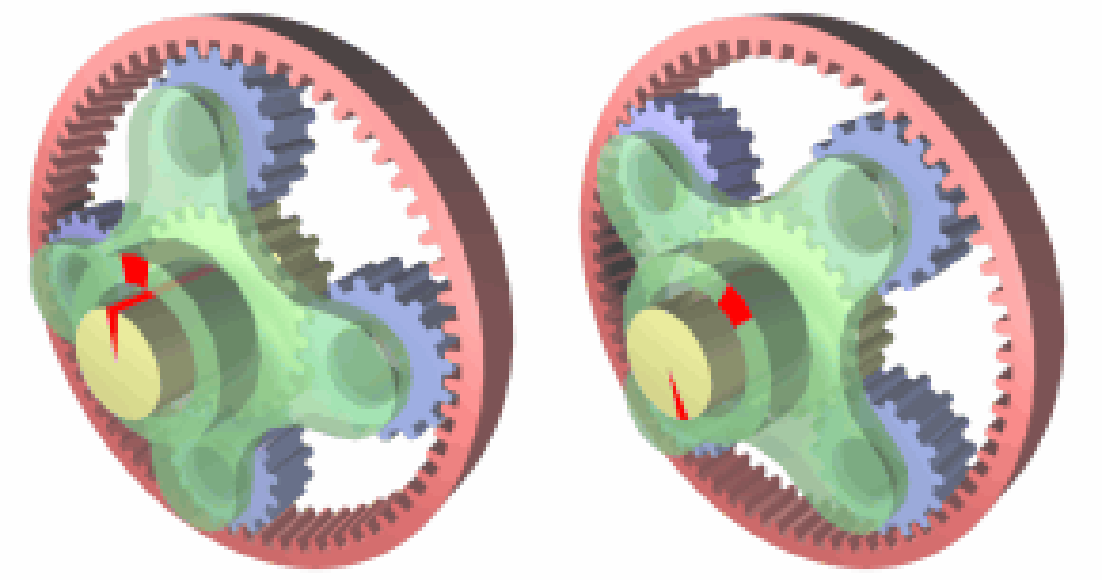
CONS:

-Low efficiency (can be an advantage in some cases: NON backdrivable)

Epicyclic gearing

Epicyclic gearing or planetary gearing is a gear system that consists of one or more outer gears, or planet gears, rotating about a central, or sun gear.

Outer gears meshes with an outer internal geared wheel



Willis formula allow to calculate reduction ratio for an epicyclic gearbox:

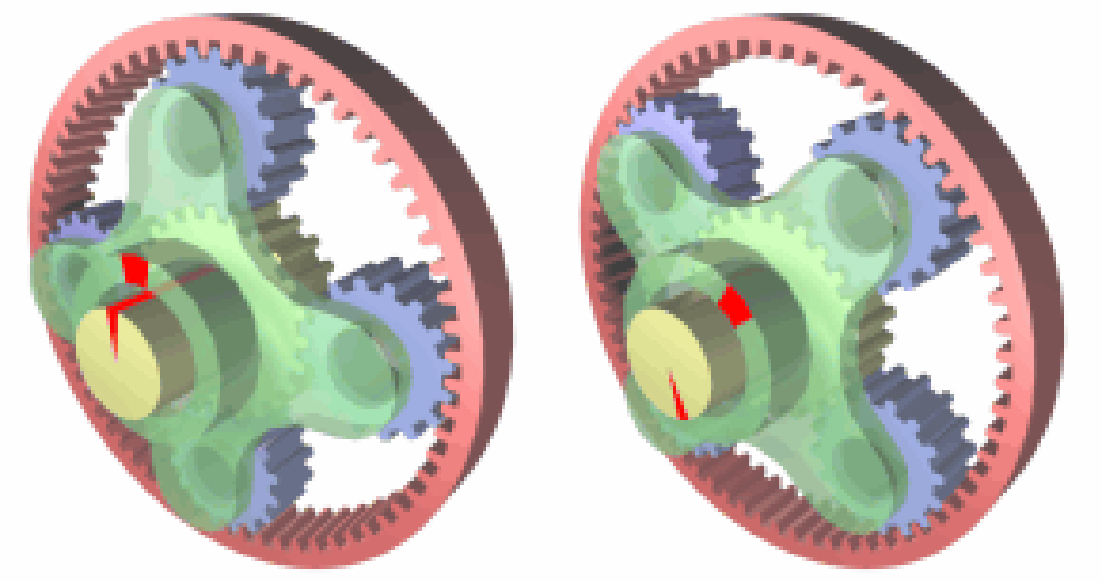
Nin/Nout = (w_out – w_arm)/(w_in – w_arm)

Epicyclic gearing application: planetary gears

Planetary gears are very common in precision mechanics.

The annulus is fixed to the frame of the gearbox. The reduction ratio is:

$I = (z_{annulus}+z_{sun}) / z_{sun}$



Fauhaber range.. (small)

Metric | English

Series	PDF	Version	Diameter (mm)	Shaft Diameter (mm)	Standard Ratios (from ... to)	Torque cont. duty (mNm)	Intermittent duty Torque (mNm)	Works with
02/1		plastic	1.9	0.5	13:1 ... 43:1	0.15	0.3	
06/1		steel	6	0.8	4:1 ... 4096:1	25	35	
08/1		steel	8	1.5	4:1 ... 4096:1	60	120	
10/1		steel	10	2	4:1 ... 4096:1	100	200	
12/4		steel	12	3	4:1 ... 1024:1	300	450	
13A		plastic	13	3	16:1...1024:1	180	220	
14/1		steel	14	3	3.71:1 ... 5647:1	300	450	
15A		plastic	15	3	14:1...23014:1	250	400	
16/7		steel	16	3	3.71:1 ... 5647:1	300	450	
20/1		steel	20	4	3.71:1 ... 1526:1	500	700	
22E		plastic	22	4	19:1.23014:1	600	1,000	
NEW 22F		steel	22	3.5	4:1...344:1	1,000	1,500	
NEW 22/7		steel	22	6	3 ,71 :1 ... 1 526 :1	700	1,000	
23/1		steel	23	6	3.71:1 ... 1526:1	700	1,000	
26A		plastic	26	6	13:1 ... 256:1	1,000	1,500	
26/1		steel	26	5	3.71:1 ... 1526:1	3,500	4,500	
30/1		steel	30	8	3.71:1 ... 1526:1	4,500	6,000	
32/1		steel	32	6	4:1 ... 2076:1	4,500	6,000	
32/3		steel	32	8	3.71:1 ... 1526:1	7,000	10,000	
34/1		steel	34	8	12:1 ... 54880:1	5,000	5,000	
38A		steel	38	10	4:1 ... 1600:1	20,000	20,000	
38/1, 38/2		steel	38	8	3.71:1 ... 1526:1	10,000	15,000	
44/1		steel	44	10	4.8:1 ... 2548:1	16,000	20,000	

FAULHABER

Planetary Gearheads

0,6 Nm

For combination with
DC-Micromotors:
2224, 2230, 2232, 2233
DC-Motor-Tacho Combinations:
2251

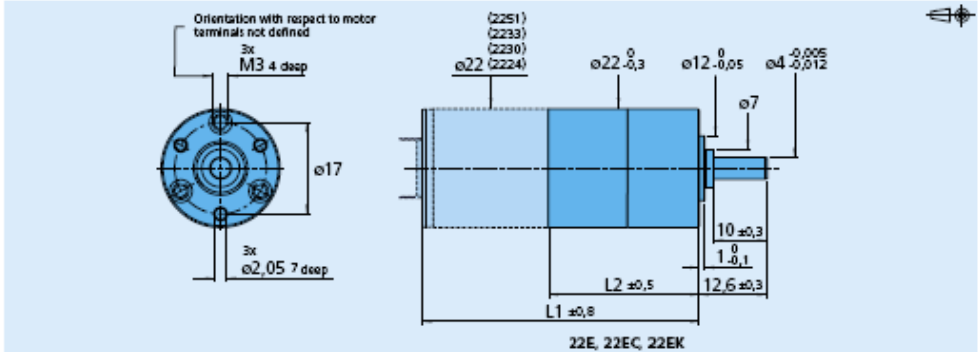
Series 22E

	22E	22EC	22EK
Housing material	plastic	plastic	plastic
Geartrain material	plastic	plastic	plastic
Recommended max. input speed for:			
– continuous operation	5 000 rpm	5 000 rpm	5 000 rpm
Backlash, at no-load	≤ 3°	≤ 3°	≤ 3°
Bearings on output shaft	sintered sleeve bearings	ceramic bearings	ball bearings
Shaft load, max.:			
– radial (5 mm from mounting face)	≤ 3 N	≤ 15 N	≤ 50 N
– axial	≤ 3 N	≤ 2 N	≤ 5 N
Shaft press fit force, max.	≤ 15 N	≤ 15 N	≤ 15 N
Shaft play:			
– radial (5 mm from mounting face)	≤ 0,05 mm	≤ 0,06 mm	≤ 0,04 mm
– axial	≤ 0,25 mm	≤ 0,25 mm	≤ 0,25 mm
Operating temperature range	– 30 ... + 65 °C	– 20 ... + 85 °C	– 30 ... + 85 °C

Specifications

reduction ratio (nominal)	motor ordering code [1]	number of gear stage	weight without motor	length without motor	length with motor 2224 [1]	length with motor 2230 [1]	length with motor 2233 [1]	length with motor 2251 [1]	output torque continuous operation	output torque intermittent operation	direction of rotation (reversible)	efficiency
			g	L2 mm	L1 mm	L1 mm	L1 mm	L1 mm	M max. mNm	M max. mNm		%
19 :1	B	2	17	27,8	51,3	57,1	59,7	78,7	200	400	–	78
28 :1	A	2	17	27,8	51,3	57,1	59,7	78,7	200	400	–	77
69 :1	B	3	19	32,8	56,3	62,1	64,7	83,7	300	600	–	69
102 :1	A	3	19	32,8	56,3	62,1	64,7	83,7	300	600	–	68
152 :1	A	3	19	32,8	56,3	62,1	64,7	83,7	400	800	–	67
249 :1	B	4	20	37,8	61,3	67,1	69,7	88,7	400	800	–	62
369 :1	A	4	20	37,8	61,3	67,1	69,7	88,7	500	1 000	–	61
546 :1	A	4	20	37,8	61,3	67,1	69,7	88,7	600	1 000	–	60
809 :1	A	4	20	37,8	61,3	67,1	69,7	88,7	600	1 000	–	59
896 :1	B	5	22	42,8	66,3	72,1	74,7	93,7	600	1 000	–	55
1 327 :1	A	5	22	42,8	66,3	72,1	74,7	93,7	600	1 000	–	54
1 966 :1	A	5	22	42,8	66,3	72,1	74,7	93,7	600	1 000	–	53
2 913 :1	A	5	22	42,8	66,3	72,1	74,7	93,7	600	1 000	–	52
3 225 :1	B	6	24	47,8	71,3	77,1	79,7	98,7	600	1 000	–	49
4 315 :1	A	5	22	42,8	66,3	72,1	74,7	93,7	600	1 000	–	51
4 778 :1	A	6	24	47,8	71,3	77,1	79,7	98,7	600	1 000	–	48
7 078 :1	A	6	24	47,8	71,3	77,1	79,7	98,7	600	1 000	–	47
10 486 :1	A	6	24	47,8	71,3	77,1	79,7	98,7	600	1 000	–	46
15 534 :1	A	6	24	47,8	71,3	77,1	79,7	98,7	600	1 000	–	46
23 014 :1	A	6	24	47,8	71,3	77,1	79,7	98,7	600	1 000	–	46

[1] Example of ordering information:
2224 B 012 SR + 22E 19:1
These gearheads are available only with motors mounted.



22E, 22EC, 22EK

Look how increasing
the number of "stages"
the reduction ratio increases
but the efficency drecreases

Alpha range.. (big)

WITTENSTEIN

		Low backlash planetary gearheads							
									
Products		**alpheno®**	**TP+**	**TP+ High Torque**	**SP+**	**SP+ High Speed**	**LP+**	**LPB+**	**alphira®**
Catalog page		24	28		66		112		124
Max. acceleration torque	Nm		6000	10000	4500	1500	450	220	200
	in.lb		53100	88500	39825	13275	3983	1947	1770
Max. speed	rpm		5500	4500	5500	4500	4000	3700	4000
Ratio	min. i =		4	22	3	3	3	3	5
	max. i =		100	220	100	100	100	10	100

Planetary gearbox

PRO:

Higher forces if compared to simple gear train same size (several gears in parallel dividing the torque);

Can be really precise (nearly zero backlash);

Can be really small (faulhaber range..);

High efficency

CONS:

Generally expensive

For high reduction ratio several “stages” must be connected in series and efficency lowers

Harmonc drive

Circular Spline

A solid steel ring with internal teeth

Flexspline

A flexible steel cylinder with external teeth and a flanged mounting ring.

Wave Generator

The Wave Generator is a thin-raced ball bearing fitted onto an elliptical plug serving as a high efficiency torque converter.

Harmonc drive – woking principle

The flexspline equivalent lenght is smaller than the outer circular spline -> it has fewer teeth

The wave generator keeps the flex spline in an elliptical shape with teeth engaging across the major axis of the ellipse

Each turn of the Wave Generator moves the Flexspline two teeth anti-clockwise relative to the Circular Spline.

Harmonc drive – range

(nb:HD was patented solution till few years ago)

Harmonic Drive offers a complete range of products for demanding applications:

The compact design of the backlash-free **Harmonic Drive component sets** allows a space-saving integration directly into machines. The component sets are available in various sizes and in different variants.	- 
Harmonic Drive Units consist of a gear component set, equipped with a high capacity output bearing, which are intended for integration into a machine.	- 
The key element of **Harmonic Drive gearboxes** is a component set within a housing with a flange or shaft as output assembly.	- 

Harmonc drive – overview

Pros:

-Good precision

-Zero backlash

-High reduction ratio in single stage

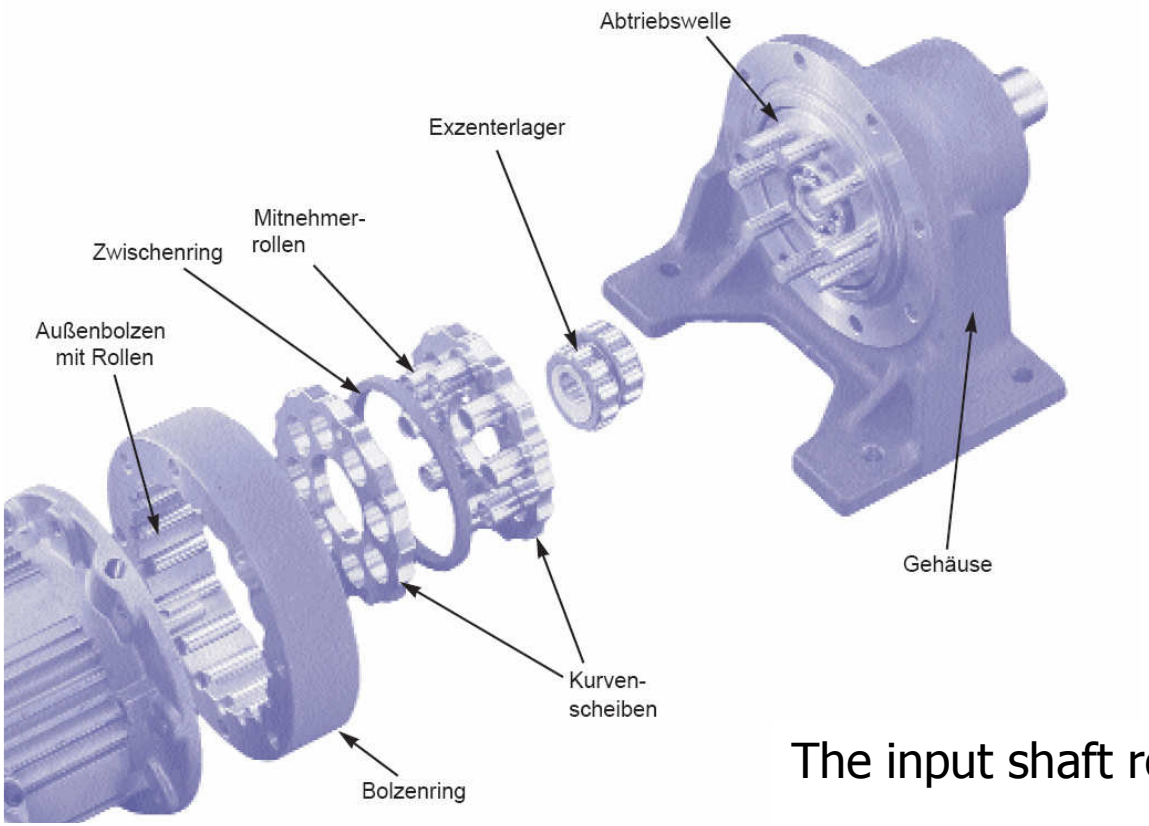
-lightweight

Cons:

-High cost

-Low efficiency

Cyclo type gearboxes – working principle



The input shaft rotates the eccentric roller

The roller actuates the cycloidal wheel which couples with an outer ring

For each rotation of the input axis the wheel counter rotate of one lobe

Cyclo gearboxes

Pros:

-Good efficiency

-High overload capacity (500%)

-High transmission ratio (up to 50 per stage)

-Zero backlash range available

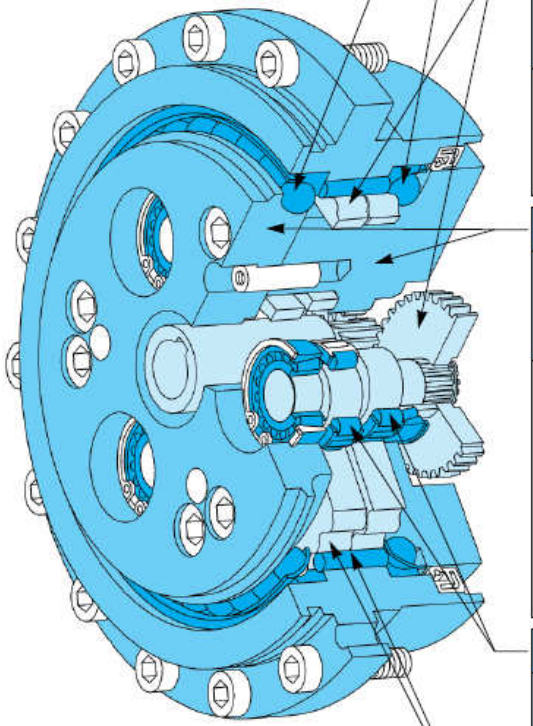
-Industrial std backlash range available

Cons:

-Heavier than HD (but bigger ranges availables)

Other brands developed solutions similar to Cyclo in the past as SPINEA, NABTESCO

Fig.1



INTEGRATED ANGULAR BALL BEARINGS

Benefits:
- Increases reliabilty
- Reduces overall cost

Attributed to:
- Built-in angular ball bearing construction improves ability to support external loads, increases moment rigidity and maximum allowable moment.
- Reduces the number of components required.
- Simplifies installation and maintenance.

2 STAGE REDUCTION

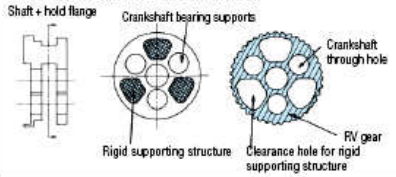
Benefits:
- Reduces vibration
- Reduces inertia (GD^2)

Attributed to:
- Low speed rotation of the RV gear reduces vibration.
- Reduced size of the motor coupling part (input gear) lowers intertia.

ALL MAIN ELEMENTS ARE SUPPORTED ON BOTH SIDES

Benefits:
- Higher torsional stiffness
- Less vibration
- High shock load capability (5 times rated torque)

Detail:
- Crankshafts are supported on both sides of the reduction gear as shown below.



ROLLING CONTACT ELEMENTS

Benefits:
- Excellent starting efficiency
- Low wear and longer life
- Low backlash (Less than 1 arc. min.)

Attributed to:
- Use of roller bearings throughout.

PIN & GEAR STRUCTURE

Benefits:
- Very low backlash (Less than 1 arc. min.)
- Higher shock load capability (5 times rated torque)

Attributed to:
- Synchromeshing of many RV gear teeth and pins.

(fine !)