Magnetal has patented solutions for unique passive magnetic bearings that enables- and improves high speed operation

Gyro Forces – An Issue?

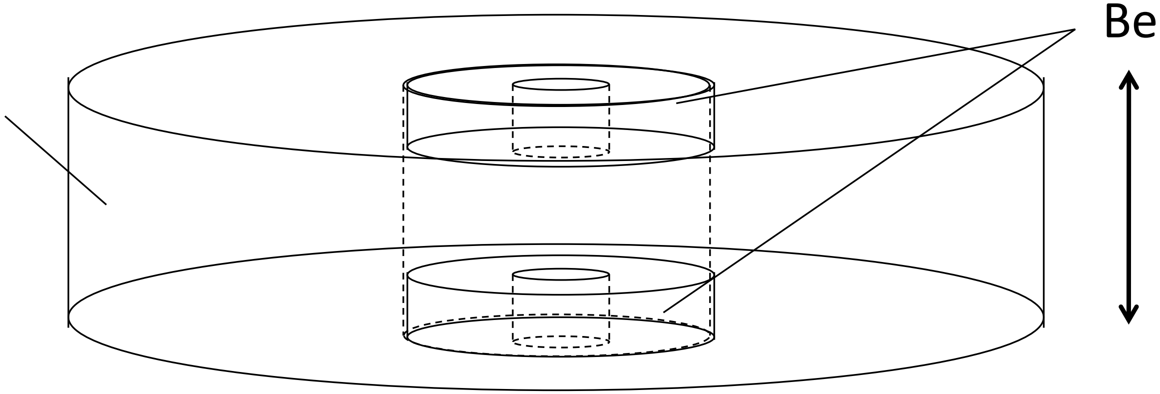
Kinetic Energy

$$E_{kinetic} = \frac{1}{2}mv^2$$

"Speed is a heavenly gift" /Gustaf de Laval

Gyroscopic Forces

An issue for flywheels?



Definitions

D_y=(FW) Outer Diameter [m]	R_Y=(FW) Outer Radius [m]	
D_I=(FW) Inner Diameter [m]	R_I=(FW) Inner Radius [m]	
Θ= Angular Speed [Rad/s]	n= Revolutions per Minute	L=Length of FW [m]
M=Momentum [NM]	I=Inertia [kgm^2]	ρ=Density [kg/m^3]

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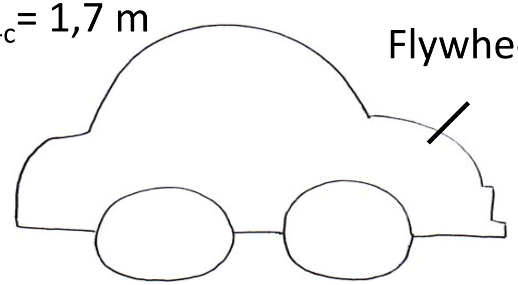
Calculation Example

Car going over a speed bump

Width (between vehicle wheels)

$W_{c\text{-}c}$= 1,7 m

Flywheel here



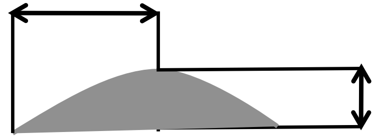
EXAMPLE: $L_{c\text{-}c}$=3,5 m

Worst Case, 30 km/h over speed bump.

V_{car}=30 km/h

L_{SB}=2 meters

Speed bump length/height



H_{SB}=0.3 meters

When the front wheel is on the way down and the back wheel is on the way up. Assume that the flywheel is connected to the chassis without springs, dampers etc. The vehicle springs and the suspensions are infinitely stiff and the vehicle is driving on its rims (no rubber tires).

The bearing force is thus 600 N for 100.000 rpm and around 300 N with a smaller FW at 200.000 rpm (same energy content).

Adding tires, suspension, dampers etc as for a real life car would significantly reduce these forces. There are other well known techniques to address and reduce these forces by (i.e. dampers, suspension, gimbal etc)

Calculation Example

Car going over a speed bump

1. Moment of Inertia $I=(\rho*L*\pi*(R_Y{}^4-R_I{}^4))/2$
2. Speed bump vertical speed $v_{vert\ SB}=H_{SB}/L_{SB}*V_{car}/3,6$
3. Angular Speed $\theta_{SP}=2*v_{vert\ SB}/L_{c\text{-}c}$
4. Torque $M=\theta*I*n*2*\pi/60$
5. Bearing Force $F_{bearing}=M/L$
6. Wheel Force $F_{wheel}=M/(2*W_{c\text{-}c})$

Gyro Forces

Table 1

Initial physical data for a rotor with an energy capacity of :					0,117 kWh	Calculated values				Speed bump 30km/hour		Forces if using rigidly mounted bearings		
Material	rev/min	Outer radius	Lenght	Density	[redacted]	Inner radius	Mass	Energy density	Moment of inertia	Vertical speed	Angular speed	Torque	Bearing Force	Wheel Force
	n (rpm)	ry (mm)	l (mm)	d (kg/m3)	[redacted]	ri (mm)	m (kg)	W (kWh/kg)	I (kgm^2)	$v_{y,front}$ (m/s)	θ (rad/s)	M (Nm)	F (N)	F (N)
Blanked	50000	*Blanked*	*Blanked*	*Blanked*	[redacted]	*Blanked*	1,64	0,071	0,0410	1,25	0,714285714	154,48	643,65	45,43
Blanked	50000	*Blanked*	*270*	*Blanked*	[redacted]	*Blanked*	1,28	0,091	0,0410	1,25	0,714285714	153,23	567,50	45,07
Blanked	50000	*Blanked*	*Blanked*	*Blanked*	[redacted]	*Blanked*	1,03	0,113	0,0410	1,25	0,714285714	153,23	510,75	45,07
Blanked	50000	*Blanked*	*Blanked*	*Blanked*	[redacted]	*Blanked*	0,85	0,138	0,0410	1,25	0,714285714	153,23	464,32	45,07
Blanked	100000	*Blanked*	*Blanked*	*Blanked*	[redacted]	*Blanked*	2,22	0,053	0,0102	1,25	0,714285714	76,61	638,44	22,53
Blanked	100000	*Blanked*	*Blanked*	*Blanked*	[redacted]	*Blanked*	1,45	0,081	0,0102	1,25	0,714285714	76,61	567,50	22,53
Blanked	100000	*Blanked*	*Blanked*	*Blanked*	[redacted]	*Blanked*	1,10	0,106	0,0102	1,25	0,714285714	76,61	510,75	22,53
Blanked	100000	*Blanked*	*Blanked*	*Blanked*	[redacted]	*Blanked*	0,88	0,132	0,0102	1,25	0,714285714	76,61	464,32	22,53
Blanked	150000	*Blanked*	*Blanked*	*Blanked*	[redacted]	*Blanked*	1,08	0,108	0,0046	1,25	0,714285714	51,08	472,92	15,02
Blanked	150000	*Blanked*	*Blanked*	*Blanked*	[redacted]	*Blanked*	1,05	0,112	0,0046	1,25	0,714285714	51,08	425,63	15,02
Blanked	150000	*Blanked*	*Blanked*	*Blanked*	[redacted]	*Blanked*	1,03	0,114	0,0046	1,25	0,714285714	51,08	392,89	15,02
Blanked	150000	*Blanked*	*Blanked*	*Blanked*	[redacted]	*Blanked*	1,01	0,116	0,0046	1,25	0,714285714	51,08	354,69	15,02
Blanked	200000	*Blanked*	*Blanked*	*Blanked*	[redacted]	*Blanked*	1,49	0,079	0,0026	1,25	0,714285714	38,31	348,24	11,27
Blanked	200000	*Blanked*	*Blanked*	*Blanked*	[redacted]	*Blanked*	1,29	0,091	0,0026	1,25	0,714285714	38,31	319,22	11,27
Blanked	200000	*Blanked*	*Blanked*	*Blanked*	[redacted]	*Blanked*	1,20	0,098	0,0026	1,25	0,714285714	38,31	294,66	11,27

Conclusions/Observations

1)The torque is a function of the rpm, energy content and the FW rotational speed. The form of the FW does has no influence on torque. The higher the rpm – the lower the gyroscopic momentum.

2) FW form does play a role for the bearing forces. A longer FW means lower bearing forces.

Conclusions/Observations

The forces on the wheels is thus pointed downwards on the right side and upwards on the left side with 11 N/wheel, (in addition to the normal vehicle load).

Basic mechanical arrangements can equalize the bearing forces to be zero.

It as reasonable to assume that the engine flywheel actually impacts the gyro forces far greater than a flywheel solution does

Summary

• The gyro forces acting on the wheels are extremely small and could probably be ignored. The forces from the engine flywheel, crank shaft etc is, by far, overshooting the forces added from a GESS-flywheel

• The faster a flywheel is spinning – the smaller the gyroscopic forces (true for the same energy content)

• Bearing forces can be greatly reduced by using normal mechanical components (dampers, suspension, gimbal etc) as well as by increasing the rpm

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