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Inertias, stiffness and eigenfrequencies

- Mechanical transmissions are not only referred to transmission ratios but also to stiffness and eigenfrequencies.
- The eigenfrequencies may be considered in different directions.
- The mass-spring model is an adequate representation to model a one-direction actuated transmission.
- The eigenfrequency, trajectory profile, and maximum vibration error are all dependent, and key factors in determining the design requirements of a robotic arm and analyzing its behavior.
- Stiffer the acceleration profile is, the stiffer the mechanics has to be.
- Multi-segment behaviors can be carried out using combinations of springs, or simulated FEM-based segments.

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Inertias, stiffness and eigenfrequencies

- Resonant frequency can be removed by considering 1) the mechanical design, 2) anti-resonant mechanical filters or 3) anti-resonant numerical filters, ….
- The smaller the robot is, the higher its eigenfrequencies (by L*)
- The quality factor measures a robot's quality independently from its size.

$$Q = f \cdot \ell$$

- A high-quality factor will allow good dynamic repeatability of the position.

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Week : Materials in robotics

Materials

Different Materials are used in the construction of robots. The aim to have the highest possible eigenfrequencies **<u>requires</u> the use of light materials with high moduli of elasticity E and of shear G**

Most often, the mechanical resistance is sufficient when the required stiffness is reached (Pay attention to buckling (Fr) flambage)

Steel

Steel : metallic alloy made of at least two elements,

- **Iron,** mainly,
- **Carbon**, in proportions ranging from **0,02 % et 2 %** in mass.

The main additional elements are **manganese** (Mn), **chromium** (Cr), **nickel** (Ni), and **molybdenum** (Mo).

Nuance	Percentage of (C)	Rupture load in MPa (P) annealed condition	Usual functions
Soft	0,15 < C < 0,20	37< P <46	structural steel, profiles, mechanical engineering, bolts, wires
Semi-Soft	0,20 < C < 0,30	48< P <55	Machine parts for mechanical applications, castings or frames, forged parts

There is not one steel but (Steel (s))
Same for Aluminium
We speak about (Alloys of aluminum and steel)

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Materials for robot segments… What to choose?

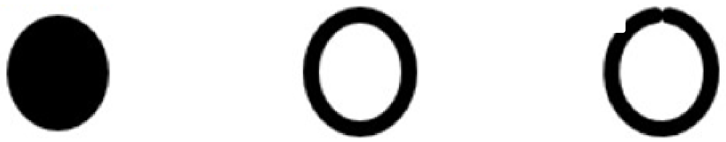
The following table shows the characteristics of materials that can be used in the construction of an industrial robot (IR).

The factor (**E/**ρ) is particularly interesting when looking for a material that is **rigid** and **light**.

Materials	E	G	ρ	E/ρ	R_m	R_m/ρ
	10^{11} Pa		$10^3 \frac{kg}{m^3}$	$10^7 \frac{m^2}{s^2}$	10^7 Pa	$10^4 \frac{m^2}{s^2}$
Steel	2,10	0,8	7,9	2,66		
Al Alloy	0,72	0,27	2,75	2,62		
Mg Alloy	0,45	0,17	1,8	2,5		
Titanium	1,1	0,41	4,46	2,47		
Copper	1,3	0,45	8,9	1,46		
Carbon fiber	2		1,74	11,5	210	121
Graphite fiber	2,7-4		1,77-1,94	15-20	280-210	158-108
Boron ® fiber	4		2,6	15,4	350	135
Kevlar fiber	1,3		1,45	9	290	200
Glass fiber	0,78		2,55	3	220	86

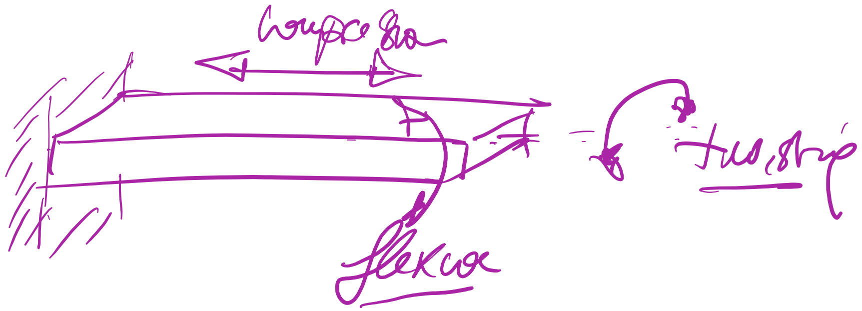
Table 2 Characteristics of certain building materials
® registered trademark by Du Pont de Nemours.

Examples:
Let’s consider the problem of creating a robot arm of 250mm with the following profile types of tubes profiles



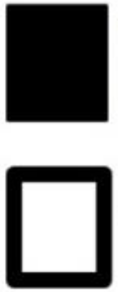
Squared tubes of side 25mm
- Full
- Hollow with 3mm thickness

Circular tubes of radius 25mm
- Full
- Hollow with 3mm thickness
- Hollow with grooves of 3mm



Examples:

Let's consider the problem of creating a robot arm of 250mm with the following profile types of tubes profiles

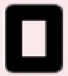
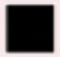


Squared tubes of side 25mm

- Full
- Hollow with 3mm thickness

Circular tubes of radius 25mm

- Full
- Hollow with 3mm thickness
- Hollow with grooves of 3mm

	Iz_g Alu [10^{-4}kg*m2]	Iz_g Acier [10^{-4} kg*m2]	Iz_0 Alu [10^{-4}kg*m2]	Iz_0 Acier [10^{-4} kg*m2]	Malu [kg]	Macier [kg]	F_flexion alu[Hz]	F_flexion acier[Hz]	F_torsion alu[Hz]	F_torsion acier[Hz]
	0,94	2,79	29,07	80,91	0,18	0,50	404	417	2759	2904
	2,22	6,33	67,84	193,83	0,42	1,20	325	336	2836	2986
	0,74	2,10	22,62	63,04	0,14	0,39	352	363	3094	3258
	1,74	4,96	53,30	151,83	0,33	0,94	282	291	3068	3231
	0,71	2,01	21,02	61,39	0,13	0,38	264	274	1007	1046

Why steel?

Steel can support high pressures. It is for that reason that all guiding elements, ball bearings, and motor shafts are for instance made of steel.

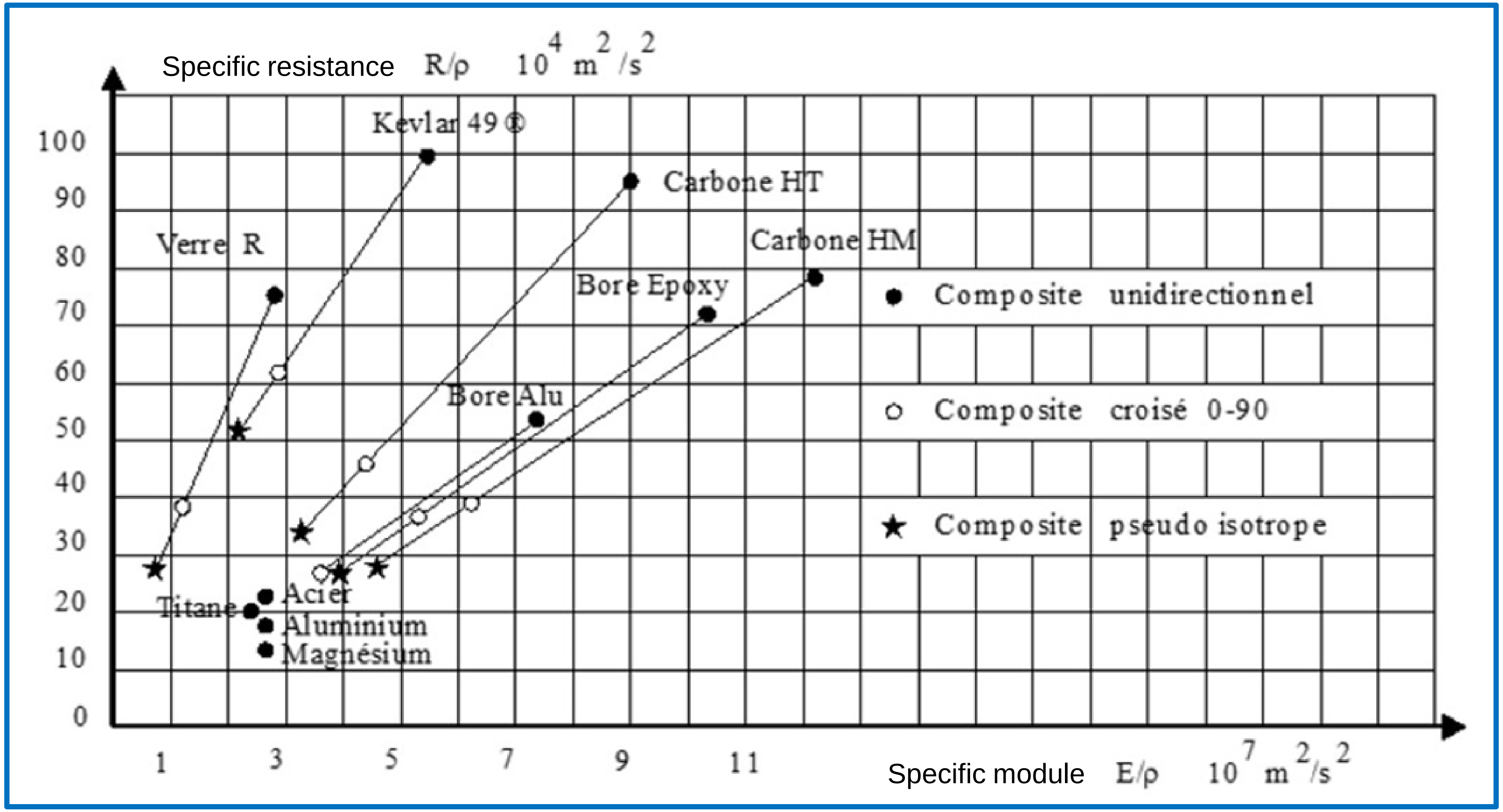
Steel is less expensive to buy but it is more expensive to machine (time and milling cutters)

What if not steel?

The use of screws for fastening in certain materials such as aluminum or plastics can cause problems with frequent tightening and loosening;

It is however possible to overcome this difficulty by
1- using insert nuts, paying particular attention to the possibilities and ease of assembly.
2- use screw-nuts assemblies

Specific resistance R/ρ versus specific module E/ρ, for different materials



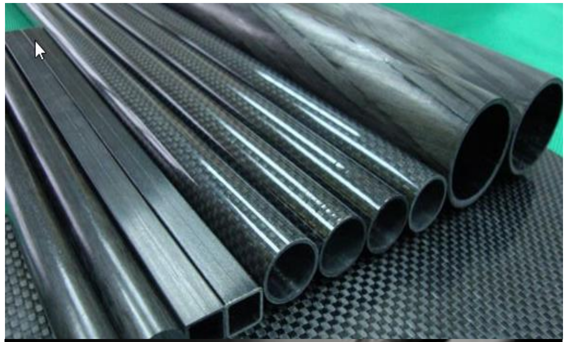
What is about carbon fibers?

The fibers are not used alone; they are usually overmolded with resin (Epoxy for example) which protects them, binds them together and distributes the load.

The agglomerate **fibers-resin** has lower values per unit mass than the basic ones. The previous table is taken from the **MELCO** documentation (Matra group) and provides additional information on this subject.

The linking of pieces in fiber (carbon or other) to other elements of construction can be very problematic if we don't want to lose their advantages; more often, this **linking is done by gluing**.

Examples





JACO™ Robotic Manipulator from Kinova technology

- Single manipulator development platform
- 6 degrees of freedom
- **Structure in carbon fiber**
- Maximal useful load of 1,6 kg
- Weight of 5.2 kg
- Easy to control
- Programme interface (API) accessible through a USB 2.0 connector
- Amplitude of 0,90 m

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http://www.nowhereelse.fr/prothese-bras-main-robotise-video-74508/

Cast Iron

Iron alloy with a carbon content between **2,1% et 6,67%** (6,67 being the max). Used mostly for the production of machine frames and stiffening of beams.

Mineral casting:(ref. Schneeberger - link)

Is being adopted for precise machine tool frames.

- Very high damping capacity.
- Very low thermal conductivity. Does not allow heat to spread between the different parts of the machine.

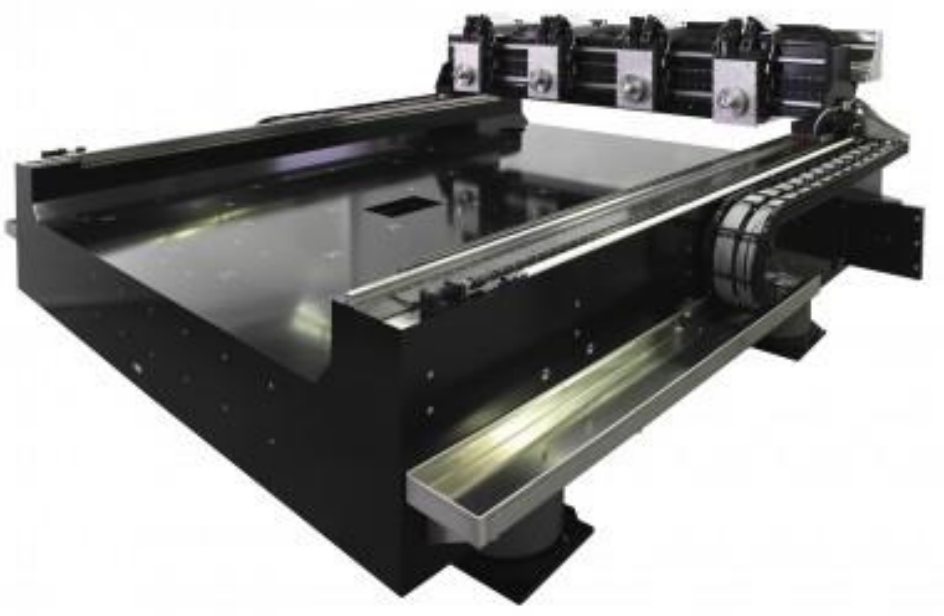

Table SCHNEEBERGER AG

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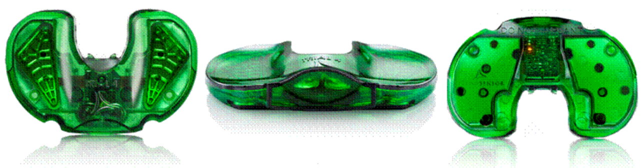
Biocompatible Materials

Can be integrated into the human body without disrupting biological processes or causing infections.

- Gold
- Titanium
- Ceramics
- Some alloys and plastics



OrthoSensor's™ Knee Balancer provides real-time, quantitative feedback on soft tissue balancing to surgeons during total knee arthroplasty. Bayer MaterialScience LLC's **Makrolon® Rx1851 plastic** provided the necessary bio-compatibility and superior strength that this application required.

Knee implant made of Cobalt Chrome alloy by laser sintering