Mechanical Technic parts and how to use them

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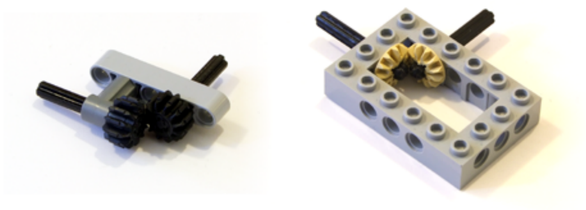
After we have devoted our attention in the previous two articles to efficiency and practical limits of static LEGO® Technic structures, we are now ready to shift our focus to moving parts. Of course, some principles mentioned in the previous articles apply in a moving context just as well as in a static one (e.g. a beam bends by the same amount under the same force, regardless of whether it actually moves or not). There are dozens and dozens of mechanical concepts and dedicated parts one can use in Technic, whose full descriptions would fill many books. That's why we will now take a look at the elementary ones, while those who seek more can satisfy their curiosity easily with various books and forums on mechanical engineering, Technic builders' websites, etc.

Since the Technic's beginnings in the 1970's, axles and gears have been the mainstay of its mechanical systems, and are still essential for a great majority of models. Let's skip the introduction about how they work in the first place, as this is something you are likely already familiar with, and look at their implementation instead.

The most dreaded occurence when using gears is skipping, i.e. having a gear and its teeth bend enough to skip over the other gear, instead of turning it, and often damaging both in the process. Of course, it happens mostly when large forces are in question, but is often a result of improper mounting. Namely, the gears should always be as close as possible (preferably directly adjacent) to the structure that holds their axles in place. Restricting axle movement from at least one side, and if possible from both when dealing with large forces, as pictured, will avoid many problems.

Building proper, strong bracing is more difficult when dealing with bevel gears (where axles are perpendicular instead of parallel), but the trick is in using compact Technic parts that are suitable for the purpose, such as rectangular frames.

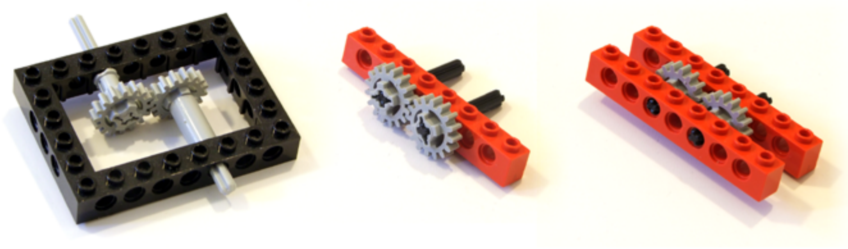


WEAK BRACING
Strength of the structure relies on a friction pin which the higher torques on the gears will dismount with ease.

GOOD BRACING
Using compact frames such as this one, the bevel gears will mesh more reliably and transfer higher torques.

However, avoiding gear skipping under high loads is just a part of the picture — keeping all the axle rotation speeds and forces in your models within efficient limits is just as important. For instance, having a system transmit lots of torque while rotating slowly, even if properly reinforced, will put it along with the underlying mechanisms and mounting points under lots of strain which may be unneccessary. Just gear it up a couple of times at the beginning and it will release the tension on its bracing, for a usually cheap price of higher rotation speed. Similarly, extreme gearing up (though, much less common) is not a solution either; high rotation speeds are hindered by friction, especially if the axles pass through plenty of parts. A bit of friction can never be avoided, but at high speeds the loss of torque becomes quite evident. In those cases it is advisable to gear the system down a bit.

There are no fixed limits on this window of efficiency, and sometimes it is impossible to keep within it anyway, due to the nature of the model — sometimes high rotation speed or lots of torque are simply required to make it work in the first place. But if you have the opportunity, try not to, for example, gear down the output of a Power Functions XL or an NXT motor, as they already produce lots of torque and can seriously strain the axles and gears on their own.



WEAK BRACING
Since their axles are given lots of freedom to bend, these two gears will start skiping at as low torque as 2 Ncm, well under what most today's motors are able to produce.

GOOD BRACING
These gears' axles are fixed well from one of their sides, significantly reducing the risk of skipping. This approach will work for a vast majority of applications.

BEST BRACING
With axle's freedom of movement limited from both sides, this is virtually skip-proof solution, but is even a bit over--reinforced for many smaller models.

On the other hand, rotation speeds above approximately 1000 RPM will start incurring noticeable friction, while above 2000 RPM a significant portion of power will be lost. This is the main reason why the early Technic motors that rotated at enormous speeds regularly required plenty of downgearing in almost every model they appeared in.

TORQUE OVERLOAD:
Avoid solutions like this one. The torque produced by the XL motor, pretty high by itself, is further increased through gearing it down threefold. The output axle has enough torque even to break some Technic parts!

When the task is to transmit rotation, chains are an interesting alternative to gears, though rarely seen. Combining various sizes of the gears they run around, they allow very easy gearing up or down, and are not troublesome when running at high speeds. However, their obvious drawback is lack of tensile strength. They tend to break when subjected to tensions exceeding about 12 N (equal to a 1.2 kg or about 2.5 lbs weight), are usually difficult to remount in a constructed model, and any reliable system should not even try getting remotely close to that limit.

While their power transmission therefore cannot match gears, chains compensate for these limits with their flexibility. Connecting axles that are at non-integer distances and difficult or unpractical to bridge with gears, are usually no problem for a chain. Connecting more than two axles is easy, too, so it is certainly worth having a couple dozen chain links handy for any Technic builder.

Belts running on pulleys behave similarly, but are less suitable since one can't choose the overall circumference arbitrarily, they pull the axles together and thus increase friction, and can usually transmit only little torque before slipping. However, this very property can make them useful for various safety systems where they will slip by design if the rest of the system gets blocked (similar to a clutch gear being used often for the purpose).

Another mechanical task required in many situations is converting the rotational motion to linear and vice versa. There are lots of implementations, and the most widely used is the rack and pinion system, spanning its LEGO® tradition from the first Technic car's (No. 853) steering in 1977. With so many vehicles built over the decades, rack and pinion has seen many forms and designs, and is supported by so many dedicated parts, that there is little left to improve. It will work in most situations, but depending on the situation, it is worth considering other options.

Where simplicity and small usage of volume is paramount, without much torque involved, a rotating liftarm like the one shown in the picture, can offer good results. Its main drawback is that small rotations in input axle usually produce very large movements at the output beam, typically requiring a gear-down stage before. Also, the rotation and resulting linear movements are not perfectly linear, unlike a rack and pinion.

For the situations where plenty of force is required, The LEGO Group has provided a dedicated part a few years ago — the linear actuator (61927c01). Its very low gearing ratio lets it reliably lift several kilograms of load if ran with sufficient torque at the input, and it is quite easy to combine several of those for even more output force. The side effect of low gearing ratio is relatively slow operation, but that is exactly what makes it particularly useful where high precision is required.

However, avoiding slack movements in Technic and obtaining precision will be the topic of the following article in the series, so stay tuned!
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Conclusions: Mechanical parts basic

● Gears need to be properly braced to avoid skipping - at least from one side, and if possible, from both. This is usually done with standard beams.
● Bracing bevel gears is more difficult, but can be done by using various compact rectangular Technic frames and similar parts
● Avoid the axles rotating very slowly and transmitting high torque, or rotating at very high speeds and carrying almost no torque - use gears to bring them into optimal working window. Otherwise, the model could be hampered by high strain on parts, or high friction.
● Where gears are impractical because of distance which is too large or of inconvenient length, consider using chains, especially if there are more than two axles involved, but pay attention not to involve too high torque.
● When converting the rotation to linear motion, rack and pinion is the most common solution and it works well in most situations, but consider rotating arms where simplicity and economy of space is important, or linear actuators where large output forces or precision are required.