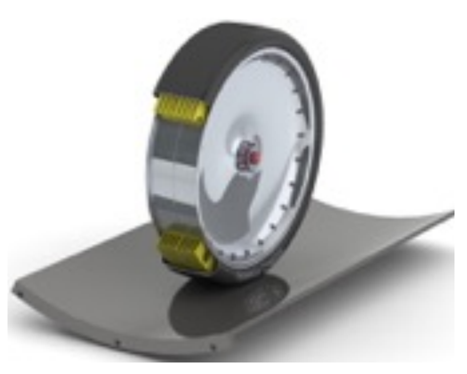
Bumps and tube accuracy

No road is smooth enough,
No railroad is straight enough,
No runway is flat enough,
Bumps are inevitable.

The manufacture of the tube is a subject not often discussed by Hyperloop engineers. But it is the essence of the project, regardless of the levitation technology used. High speeds require extreme accuracy in the running surface, here is a discussion of how to achieve it.



The need for resilience in the levitation technology
Because bumps are unavoidable, we need resilience. Maglev has a gap up to 20mm (3/4”), and has good bump tolerance. Alpha’s air skis with a clearance of only 1mm (1/16”) or less would have no bump tolerance. Steel-on-steel wheels would have problems with bumps. Pneumatic tires or metal wheels on a resilient surface would have good resilience and bump tolerance.

- **Make the tube as accurately as possible**
- **Have resilience in the levitation**

The Trajectory
The trajectory is the initial design of any Hyperloop system. It is a free-flowing curve, with horizontal curves and vertical curves in hilly country. It is a compromise between passenger comfort, speed, and the capital cost of the tube.

In hilly country, high speed will require many tunnels and flyovers. If lower speeds are acceptable, capital cost can be reduced. All the curves must have gentle lead-ins for passenger comfort, it should feel like a carefully piloted aircraft in smooth air.

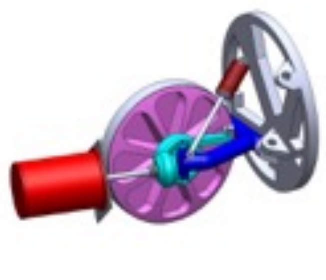
Achieving the Trajectory
The tube will be in sections, bolted of welded together. For a 2.8m ID tube, the sections could be 25m long. Each section joint is fixed, possibly on pylons, supports if close the the ground, or supported inside a tunnel.

So the tube is positioned every 25m, with every support adjustable. With modern laser positioning, combined with bump recording from the pods, it should be possible to align each support within a few mm of the ideal trajectory. So the pod passengers should not feel any bumps from the tube positioning.

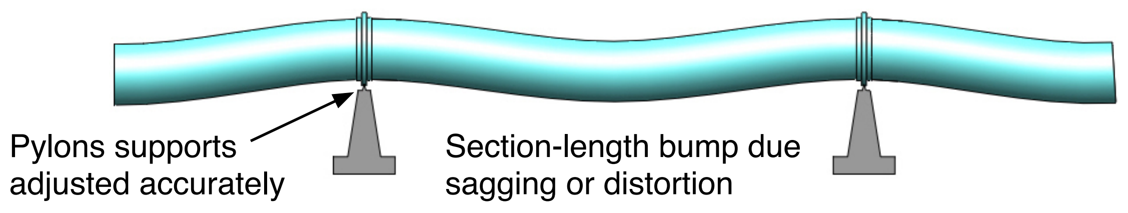
The tube supports should have remote adjustment, either system-wide, or at least from inside the tube. This way, any inevitable subsidence can be adjusted out. The Shanghai maglev was built in soft ground, and had piles down 90m to avoid subsidence. With no adjustment of the heavy concrete overpass, the ride is still rather bumpy.

What size bumps are acceptable

The acceleration rate of the suspension can be calculated. For a 10 tonne pod, the spring load on each wheel is 2,500 kg. If the unsprung weight of the wheel etc is 250 kg, the max acceleration is 10 g. So any bump greater than 10 g would cause the wheel to jump, and land back with a crash. A resilient tire or liner in the tube would help to absorb the bump.



Long bumps over a 1km length would not be absorbed by the suspension, and would just cause passenger discomfort. A 500mm bump over 1km at 1,200 km/h is an acceleration of 0.2g over a period of 3s. This would be annoying to the passengers. But the pylons can be built and adjusted to a few mm, so the problem should not exist.



Section length bumps are the result of inaccuracies or sagging in the tube sections. At 1,200 km/h, 13 sections are traversed per second. With a 25m long section, and a 10mm deflection, the wheel acceleration would be 7g, about the maximum for a solid wheel. This deflection could be absorbed by a pneumatic tire, or partially by a resilient tube lining.

Short bumps are a serious challenges for high-speed transport. A 0.5mm bump over 4m could be easily caused by a section joint, wear, or welding distortion. But this requires a 13g acceleration, and would cause a steel wheel to jump, causing slippage, hammering and further wear. This highlights the big challenge of steel-on-steel. A resilient liner in the tube, with an average deflection of 3 mm, would absorb 1 mm bumps with no problems.

Making the tube accurate
The requirement is to fabricate a 2.8m diameter tube, 25m long, then to machine it, or form it, to an accuracy of about 5mm. Extremely challenging. All of the processes described here require massive equipment, but a pair of 600 km Hyperloop tubes is a big project.

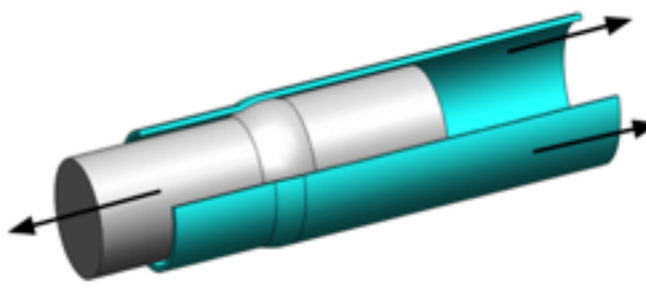
Precision fabrication of the tube over an internal mandrel would give an accuracy within about 20mm over the length.

Deflection due to gravity and thermal expansion
The large diameter tube is very stiff. For a 25m long section of 2.8m diameter, 25mm thick:-
The sag due to its own weight is only 2mm, if both ends are simply supported.
If the ends are joined to the next sections, this deflection reduces to about 0.4mm
The weight of a 10 tonne pod is small compared to the 43 tonne tube.
Thermal expansion, due to the sun on top, would have a negligible effect on the tube straightness.

Cold Forming
The tube could be precision welded, then cold formed to the correct dimensions. This is the process for normal hard-drawn tubing, which gives good accuracy and improved strength. There are a number of methods, it is a question of choosing the most suitable.

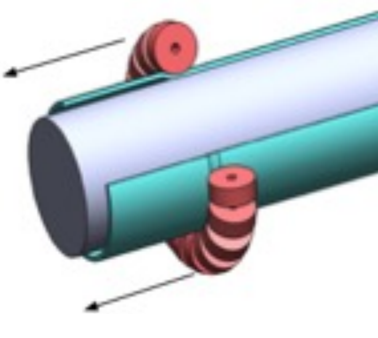
Here the tube is fabricated a little smaller, and a mandrel is pulled through to open it out to size

The tube surface is coated with a soft metal like lead, to act as a lubricant.



In this process the tube is fabricated a little larger. The rollers swage to the metal down to the size of the mandrel.

There is generally an outer metal die, rather than the rollers, but the energy becomes very high.



Other cold-forming process could be used:-
- **Spinning** where a rotating tool or roller forms the tube against a internal or external die.
- **Expanding mandrel**. A 2-piece mandrel is hydraulically expanded, to stretch the tube to shape
- **Hydro-forming**, where extreme pressure is used to expand the tube into a larger die.

Machining an accurate surface

The whole inner surface of the tube could be machined. After welding, the tube retains stresses, and after each pass of machining, the tube shifts a little. So many passes are required for accuracy, and there is a big waste of steel.

Machining the whole surface would be expensive. Following is a better option.

The tube is precision-fabricated, then steel bars are welded to the running surface.

The steel bars are then accurately machined.

Then the gaps between the bars are filled with a tough filler like epoxy, which is capable of taking the compression loads of the wheels.

Then a rubber or PU liner is fitted.