Tetra-Motion – Every Which Way

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Gantry Design – What material to use?

Designing a router gantry is a complex task if you want an optimal solution. How stiff does it need to be? How big or small does it need to be? What material to use, aluminium, steel, timber, carbon fibre or plastic?

I won't do much stress analysis in this article just a general overview of whats possible.

Usually we create a design loadcase that includes tool loads and deflection limits that have to be acheived. The structure is "stressed" very low due to the high rigidity that has to be acheived to minimise toolpath deflections, so actual stress failures do not happen. On an XYZ gantry machine the two worst conditions are both when the spindle is in the middle of the gantry. Condition 1 – is the tool cutting orthogonal to the gantry and Condition 2 – is plunging especially into aluminium. Typical drill press & mill tool loads are well over 120kgf which can only be acheived in routers with very big gantries and motors. Personal use machines and light duty commercial machines usually have around a 20kgf potential push or much less.

So we are designing a machine and we need to have a gantry. We look at the standard size aluminium and steel sections and quickly realise that aluminium gives us the lightest answer but is it the stiffest answer? We shall find out.

The gantry needs to be rigid and in engineering terms "Rigidity" is the combination of material stiffness and its geometic modulus. This is expressed as R=EI, where I is the second moment of inertia of the section, expressed as mm^4 and E is in GPa. So the units we shall use in this article are rigidity = R=GPa.mm^4. If the calculated R for section A is larger then section B then section A is more rigid or commonly said as, "its stiffer then section B".

Firstly to look at material stiffness and their densities as a number:

aluminium	70GPa	2700kg/m^3
steel	205GPa	7800kg/m^3
F17 plywood	14GPa	700kg/m^3
Plastic	4GPa	1100kg/m^3
Carbon Fibre	80GPa	1500kg/m^3

Steel is very stiff but very dense (heavy), carbon fibre is moderately stiff but very light and the other materials are in the middle. So how do we make a start on this? Lets pick a few steel sections and make a rigidity chart as a benchmark. We shall also consider the gantry as square to make the math easier. We shall also put aside the considerations of mechanical play, motion inertia, friction and losses in the system, geometric instability of thin sections, weldability and cost to keep the discussion at a very simple level. Its unlikely that the readers out there are considering a gantry as big as 300x300mm so we shall pick that as our top size. Being steel lets make it 3mm thick as this is a reasonable thickness for the job. So we shall benchmark 50x50x3 SHS, 100x100x3 SHS, 200x200x3 SHS & 300x300x3 SHS steel sections and see how we go. The weight (W) of the section will always be in kg/m and R will be expressed as GPa.mm^4.

In the table below I have calculated the equivalent rigidity of the steel section in the selected material and its resulting kg/m weight. All column entries in the below table have the same rigidity so would deflect the same if used for a gantry.

Steel benchmark	50x3mm SHS	100x3mm SHS	200x3mm SHS	300x3mm SHS
Steel R / W	4.17e7 / 4.39	3.65e8 / 9.10	3.06e9 / 18.40	1.05e10 / 27.79
Alum 3mm thick	70mm / 2.16	140mm / 4.45	282mm / 9.05	424mm / 13.66
Ply 17mm thick	75mm / 2.78	139mm / 5.85	267mm / 11.94	393mm / 18.03
CF 3mm thick	67mm / 1.14	135mm / 2.36	270mm / 4.8	406mm / 7.26

The weight of a gantry is important as it has to be moved by the motion system. The lighter the gantry the smaller the motors need to be and the faster the gantry can be moved against its own inertia. In the case of big, long span machines the self weight deflection has to be considered as well. So minimising the gantry weight is always a good idea.

The table shows why the aerospace industry prefers carbon fibre. It makes remarkably lighter structures then steel or aluminium. Packaging sizes of bearings, clamps and motors means that the gantry has to be a particular size. Once we know the packaging sizes we can pick a beam thats bigger then the packaging requirement that fulfils the structural requirement or the packaging size may do the job! This is calculated from the applied load using a beam formula or FEA.

The pick for lightest gantry that is economical is made between ply and aluminium. Timber and engineered timber is a common choice for housing and industrial construction. Timber is a sustainably green product but aluminium gets criticised due to the high energy levels required for its production. But to be fair, once made aluminium can be recycled as needed very effectively.

Timber negatives for routers in an industrial circumstance are: it can change shape due to humidity changes. This means the surfaces have to be sealed or plasticised to reduce this effect. Connections are not as convenient in timber as bolts can crush the timber. Setting fasteners with adhesives, using thread inserts and bonding joints can solve this issue.

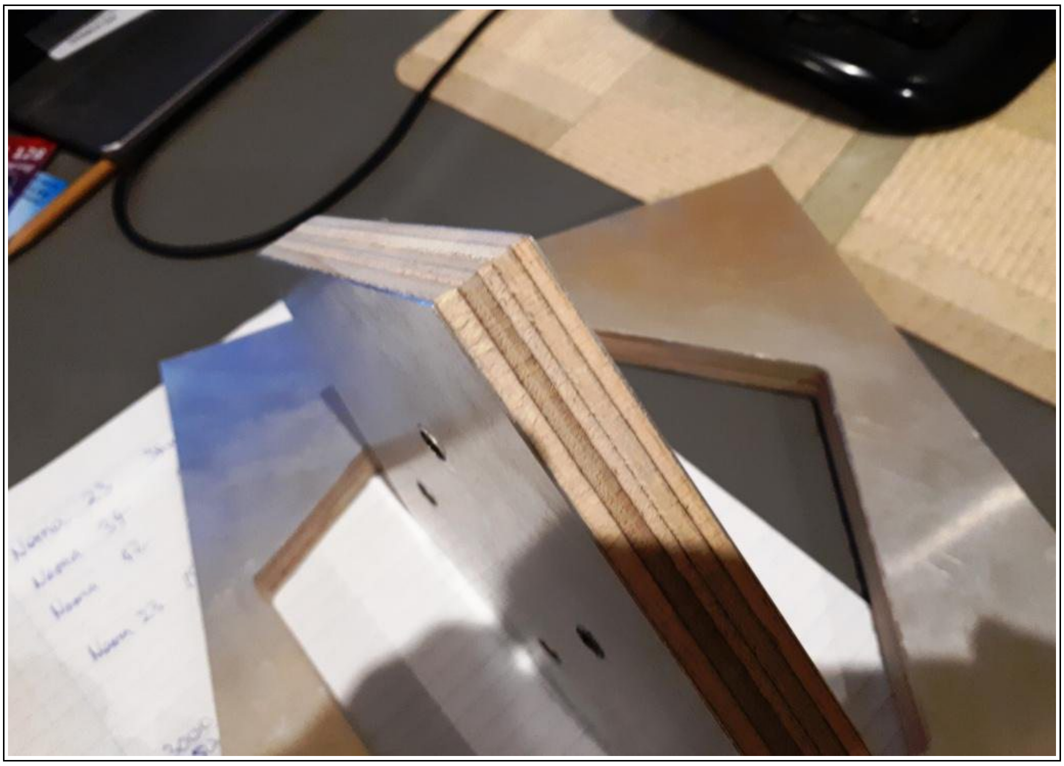
Aluminium and plywood are easy materials to work with. They are easily cut, drilled and shaped. So this seems to be the sweet spot in this investigation. This is why aluminium and timber are chosen for many structures, in many applications.

Our 17mm thick plywood (12kg/m^2) can be thought of as a10mm thick piece of aluminium (27kg/m^2) in bending if you do the math. So its a sturdy chunk of material yet it is lighter then our 10mm thick piece of metal.

Best of both Worlds

To take this one step further why not combine aluminium and timber into one structural element? We can create sandwich plates from al/ply/al and this provides very stiff structures at low weight. For instance a laminate of [2mm Al/15mm ply/2mm Al] has the same bending stiffness as a 15mm solid aluminium plate yet is 1/3 the weight of a solid 15mm thick aluminium plate. Tetra-Motion has taken advantage of this fact and makes as many parts as possible using aluminium laminates. Tetra-Motion makes its laminates in-house to various specifications. The aluminium also prevents dimensional changes due to moisture effects. A win all round.

Happy to answer any questions out there...



An aluminium and ply laminate test cut.