Fastening for Function

by Peter Standring

Everyone knows the term 'fastening' means to secure. In the vast majority of fasteners, this is exactly what they do – 'secure'. However, not all fasteners provide total lock down basically because they were designed not to.

In mechanical design, constraint from and movement of various elements are key to the successful function of any assembly. These kinematic motions are defined in 3D space using the six degrees of freedom (SDF) of translation and/or rotation along/round the cartesian axes x, y and z as shown in Figure One. It may be a fanciful story but the Grandmother of Rene Decarte, 17th century mathematician, philosopher, soldier etc., claimed that as a teenager, her Grandson's back seemed to be glued to the bed. If the youngster was indeed idle as his Grandmother suggests, it is not difficult to imagine him lying on his back on his bed whilst he thought great thoughts. For example, "I think therefore I am". Perhaps then, with one leg crossed over his bent knee and looking at his big toe, he considered how he might extend Euclid's ideas on space to determine the position of his toe in the room. Selecting as his reference axes the edges of the walls and floor he invented the cartesian coordinate system?

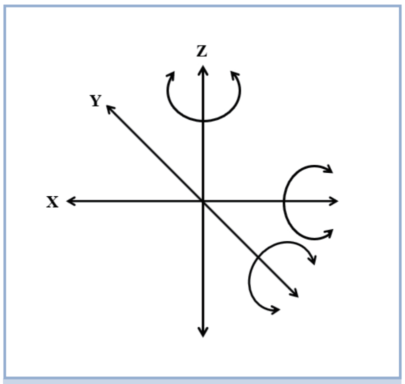


Figure One: Six degrees of freedom in 3D space (Three Translations along X, Y and Z; Three Rotations around X, Y and Z).

Machine tools and associated equipment in which movements are allowed or constrained provide many examples of the importance of the SDF in design.

A classic case is a flat, rectangular surface table which to function properly must remain in the horizontal plane and be constrained from lateral movement or rotation around the vertical axis whilst being free to expand and contract horizontally if the temperature varies. A well known elegant solution could be to have three vertically adjustable ball feet attached to the underside of the table and positioned to form a large isosceles triangle with its base parallel to the width.

The table support frame might have the ball at the top of the triangle located in a conical hole. At the base, one ball would sit on a flat surface, the other in a vee groove aligned to the long axis of the table. By this means, the ball in the conic hole would prevent translation along the x/y axes, the ball in the groove would prevent the table from rotating about the z axis and the ball on the flat would allow the plate to expand or contract without constraint.

The fundamental geometric design of the lathes, milling machines etc., are all based on the SDF principle. OK, so what about fasteners?

Flexible Fasteners

The term 'flexible fasteners' may seem to be a misnomer yet such things exist everywhere. A child's helium filled party balloon is 'fastened' at the neck and tethered by a string to prevent it flying away. Likewise with a boat, a horse, a flag and a laced shoe. However, in such cases, the 'flexibility' of the fastener is only made possible by the material used to make it. In the cases presented in this article, the 'flexible fasteners' will be made of metal. All are commonly encountered both industrially and domestically and without them, life would be unimaginably different.

From consideration of the SDF it is clear that to embody flexibility in a fastener, it must allow translation along certain cartesian axes and/or rotation around them. For translation only, this could mean in, x, y or z; in xy, xz or yz, also in xyz – seven possibilities in total. Exactly the same is true for rotation. So if we can combine those together, we naturally end up with 49 different possible options for fastener flexibility.

Since motion along or around one axis is the same as for the others, it is a simple matter to rationalise the 49 options down to 15, three of which are uni-directional, five which are Planar and seven in 3D. Table One lists the 15 motions.

Type	Motion	Axes	Number of Motions	Number of Dimensions	Applications
1	T	X, Y OR Z	1	1	spring loaded pin
2	R	X, Y OR Z	1	1	scissor
3	T (1+2) R	X, Y OR Z X, Y OR Z	2	1	bayonet fitting
4	T	XY, XZ OR YZ	2	2	scotch yoke
5	R	XY, XZ OR YZ	3	2	gimbal
6	T (4+2) R	XY, XZ OR YZ X, Y OR Z	3	2	scotch yoke with hinge
7	T (5+1) R	X, Y OR Z XY, XZ OR YZ	3	2	selector fork
8	T (4+5) R	XY, XZ OR YZ XY, XZ OR YZ	4	2	double acting bolt
9	T	X, Y AND Z	3	3	scotch yoke with spring loaded pin
10	R	X, Y AND Z	3	3	ball joint
11	T (8+2) R	X, Y AND Z X, Y OR Z	4	3	scotch yoke with rotating peg
12	T (9+1) R	X, Y OR Z X, Y AND Z	4	3	spring loaded ball catch
13	T (8+5) R	X, Y AND Z XY, XZ OR YZ	5	3	five way linkage
14	T (9+4) R	XY, XZ OR YZ X, Y AND Z	5	3	ball joint with scotch yoke
15	T (8+9) R	X, Y AND Z X, Y AND Z	6	3	ball joint + scotch yoke + spring loaded pin

Table One *Rationalised Six Degrees of Freedom for 'flexible' fasteners.*

Colour code *Uni-directional,* *Planar,* *3D*

It must be recognised that it is the fasteners which hold mechanical assemblies together so they can perform the design function. These couples are normally referred to as 'sliding pairs' or 'screw pairs' e.g. as in a leadscrew and nut on a lathe. For reasons of alignment in Presses, Prothesis Joints and Constant Velocity Joints the sliding motion is often rotational.

Column One in Table One identifies each type of flexible fastener. Column Two states the motion a flexible fastener is required to carry out in terms of (T) for Translation, (R) for Rotation along or round a given axis. In fasteners where both T and R occur, the individual fastener Types involved are shown in brackets e.g. for Type 3 the combination of T and R is shown as Types (1 + 2).

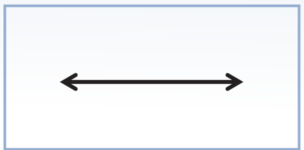
Column Three lists the axes (x, y and z) along or around which the fastening device allows Translation and/or Rotation.

Column Four indicates the Number of Motions which occur in accomplishing the task.

Column Five identifies the Number of Dimensions in which the fastener moves, (1) being Uni-directional, (2) being Planar and (3) being 3D.

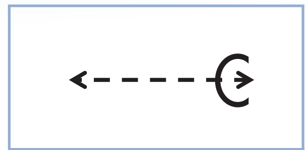
Column Six provides some well known Applications for the use of flexible fasteners.

For a Type 1 flexible fastener moving along a single axis this could be a spring loaded actuator for a pawl or cam device.



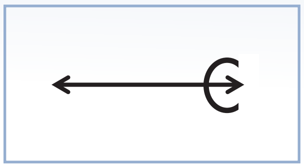
T along X, Y or Z.

A Type 2 fastener would be a common scissor joint or ball valve rotation around one axis.

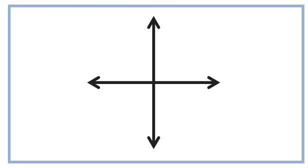


R around X, Y or Z.

Type 3 is simply a combination of Types 1 and 2 as in the case of a bayonet fitting, a rifle bolt or a toggle. All three represent uni-directional motion.



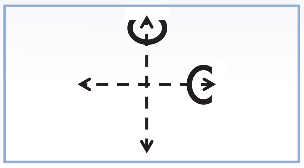
Type 4 where movement occurs along two axes in a Plane, is commonly found in mechanical transfers systems like the well known 'Scotch Yoke.'



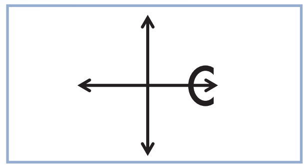
Types 4 to 8 inclusive are flexible fasteners which operate in a Plane.

3D flexible fasteners are found where Translation and/or Rotation take place on all three axes and relate to all following fastener types.

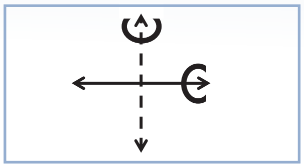
Type 5 where rotation takes place round the two axes is the basis of a ships compass 'gimbal' and some types of hot and cold water mixer taps.



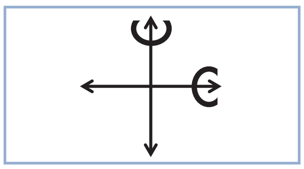
A Type 6 fastener device simply links a 'Scotch Yoke' with a hinge to effect Planar Translation with Rotation around one axis.



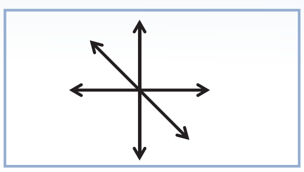
Type 7 is the same as Type 6 but takes place where Rotation occurs around two axes and Translation along only one. This could be achieved by the actions of a selector fork fastened to an actuator rod.



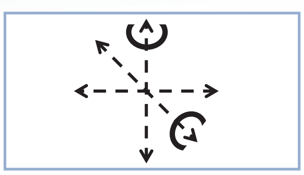
Type 8 combines Types 4 and 5 having both Translation and Rotation along and around two axes. This could be obtained by a double acting bolt.



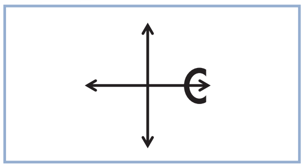
Type 9 is simply a Type 4 plus a Type 1 which could be a 'Scotch Yoke' with a spring loaded actuator operating in the z direction.



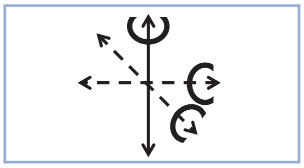
Likewise with Type 10 where 3 Rotations could be satisfied by the actions of a ball joint device.



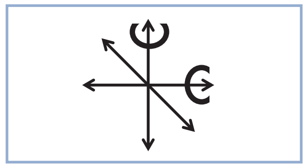
Type 11 could be a 'Scotch Yoke' plus a rotating peg.



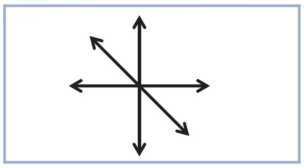
Type 12 is simply a spring loaded ball catch.



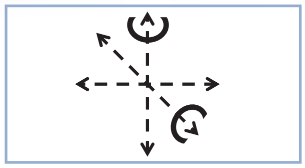
Type 13 requires three Translations and two Rotations which could be met by an old aircraft control linkage.



Type 14 by a ball joint (three Rotations) and a 'Scotch Yoke' (two translations).



Type 15, with three Translations and three Rotations by a ball joint, 'Scotch Yoke' and spring loaded peg acting as a single unit.



In short, there are a multiplicity of examples from jewellery to space age gyroscopic devices where fasteners are required to demonstrate flexibility in their operational functions. To define these using the SDF could help link the design intention to the ease of manufacture.

And Tomorrow?

This, hopefully thought provoking article, will encourage those designing and using fasteners to think of them in a wider perspective of their function rather than simply to secure.

The cleverest of devices always combine simplicity with effectiveness and are rarely improved upon. For example, the humble paper clip which is likely only to become redundant when we live in a totally digital world!

Simple umbrella catches are a classic case where a flat, spring loaded protuberance from a slot on the hollow shaft is both constrained in space yet allowed to function by the geometry of the pressing it is part of.

The hardened ball in a pen functions in the same way as does a virtually friction free table or conveyor used for moving heavy press tooling. It could also relate to a telescope or goniometer mounting.

Actuator pins, shafts and sliding elements of all descriptions are maintained in their 'functional' space by fastening with: keys, splines, circlips and shear pins etc.. In all cases, it is the SDF which are used to define the elemental constraints to ensure the fastener fulfils its design function.

Could the world exist without the use of metal based flexible fasteners? The question is not a philosophical exercise in lateral thinking but a genuine attempt to gaze into the world of tomorrow. Additive manufacture offers many potential benefits for exploitation in mass manufacture.

The novelty factor of designing parts which cannot be made using conventional methods of manufacture have expanded from the production of polymer prototypes to high value metal based and ceramic aerospace and other high tech products employing techniques like laser sintering. Cost reductions will evolve to meet the insatiable demand for next generation goods each either fitting into the common DNA of manufacture or occasionally mutating into a new and 'disruptive' strand.

Key to all this is the design function which will inexorably lead to fewer assembled parts to reduce both manufacturing and inventory costs improving efficiency (however that is measured) and in the process 'distilling' the function into its simplest form.

The elegance of Decarte's cartesian axes in describing 3D space has not been replaced in almost 400 years. Like the use of zero in mathematics, it opens up so many opportunities to use it and to discover more. The SDF are fundamental to the ways in which engineers design mechanical systems using CAD and CAE. The natural extension of design directly to modern 3D manufacturing techniques clearly impact on how things function, how they are made and where necessary, are held together. For this reason, if for no other, the manufacturers of 'flexible' fasteners would do well consider how their future may be changing right now. ■