

Clever fastening by forming

Dr Peter Standring, Industrial Metalforming Technologies (IMfT)

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Clever fastening by forming

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That we live in a digital age is apparent by the sight of so many of our fellow humans being glued to their smartphones. Yet it is barely half a century since metalforming was supplanted by electronics after at least three millennium of maintaining its strategic position in both expressions of wealth and weapons of warfare.

Factories employing just a few to many thousand of workers, all bent on transforming metal into a myriad of similar products, have all but disappeared from the developed world. A tiny proportion of modern, super efficient manufacturing sites now exist producing countless times more output than those belonging to previous generations.

The reason and probably the primary driver of 'globalisation' is the concept of 'standardisation of products' based on classification and rationalisation. Previously, everyone and their dog had their own brand of 'widget' but today, all 'widgets' are the same. Hence, output goes through the roof and the costs of production tumble. Exactly the same principle can be seen in the current online market where increasingly sophisticated software uses real time data to identify current trends in demand and use this to influence output.

So, if all 'widgets' are both cheap and plentiful, what additional criteria can be used to make them worth manufacturing? At present, environmental issues (energy, lightweighting, waste, end of life) can be factored into the manufacturing equation. With these issues in mind, the type of 'widget' used in an assembly of multiple widgets becomes a complex task, which should, if it is carried out correctly, involve a multifunctional design/manufacturing team. Getting the product right and fit for its functional life is crucial. Getting it wrong can be exceedingly costly (e.g automotive vehicle recalls).

Standard widgets, knocked out at superfast speeds, will always be cost-effective but instead of having one 'widget', could a number be assembled together to provide the customer with much more value? In metalforming terms, the basic processes of rolling, forging, hollow extrusion, etc, produce standard products and parts in huge quantities. Because they work over a large cross sectional area, they naturally require very large forces to accomplish the desired deformation. Other more sophisticated metalforming processes – such as spinning, roll forming, swaging, profile rolling and rotary forging – all use much smaller contact zones between the forming tool(s) and the workpiece. Therefore because the force required to achieve deformation is directly proportional to the yield stress of the material being shaped, it follows that these 'incremental' forming processes use much smaller forces. This means machine sizes can be proportionally smaller than their conventional counterparts.

It has long been recognised that incremental deformation processes (IDP) can play a significant roll in fasteners and fixings. Thread rolling of course in its many guises is an incremental process, but that produces an independent fastening item. The role of IDP referred to here, is one in which a finished product is deformed and by doing so, also simultaneously fastens.

Perhaps the most common and widespread fastener of this type is the humble, yet significant, rivet which is almost always deformed incrementally (self-piercing and pop rivets may be exceptions). Mechanical devices to aid the riveting process have long been produced but one of the most successful, with a pedigree going back over 100 years, are those termed as rotary riveting machines.

Rotary riveting machines

The concept of rotary riveting basically replicates the action of using a hammer to 'peen' the head of a rivet. However, instead of using multiple individual blows, such as in rotary riveting, a tool is placed with its axis inclined in a spinning head. The simple principle – shown in Figure 1 – can have a number of variations, which have been classified by using the Euler Angles of nutation, precession and spin. Figure 2 shows how these angles are used to describe the 'tilt' of the Earth's axis (nutation); the 'precession' of the Earth's axis and the 'spin' of the Earth about its own axis.

Figure 1: Principle of rotary riveting

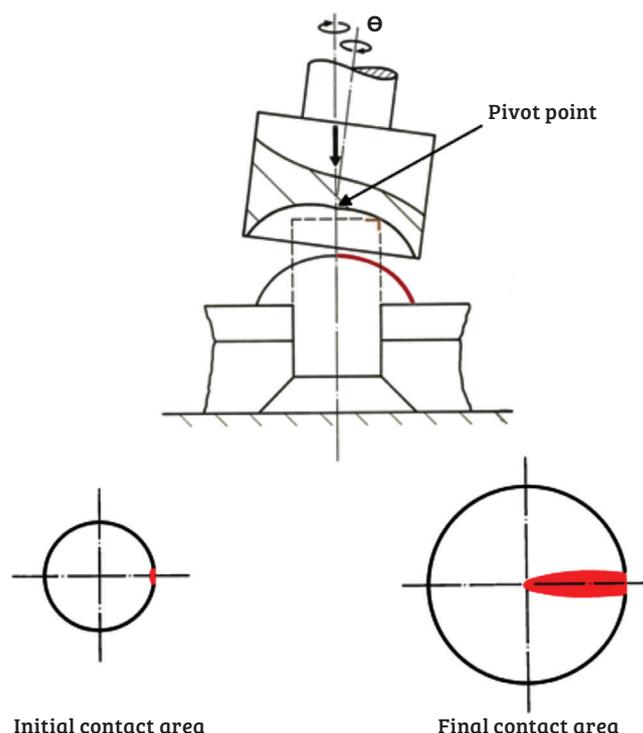


Figure 2: Tilt of the Earth's axis (nutaton angle)

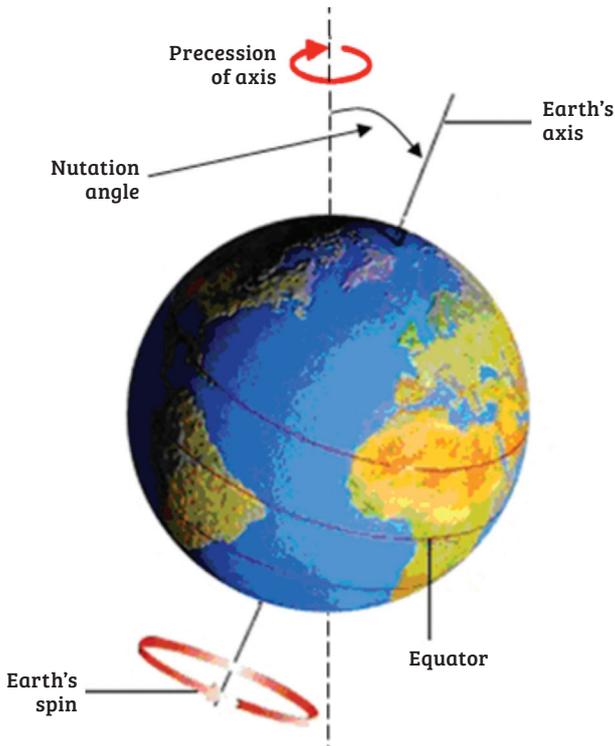
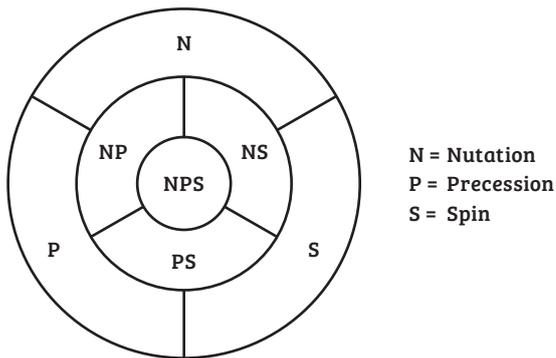


Figure 3 identifies the complete family of rotary riveting machine designs and Table 1 illustrates various examples of these embodiments as they were developed. It should be noted that where multi axis motions are involved, the designs shown in Table 1 are achieved by mechanically driven movements either directly or as a result of tool/work interaction (Figure 1).

Figure 3: Classification of all rotary riveting machine motions based on the Euler Angles of nutation, precession and spin



In all rotary riveting machines the key element is the position of the intersection of the spinning head and tool axes. This is generally termed the 'pivot point' of the design and for sound kinematic reasons, must lie on the tool/workpiece interacting surface. As will be appreciated, the geometry of the riveting tool and the movement of its axis will determine the shape of the formed rivet surface. A 'gull winged' tool would be required to produce a hemispherical rivet head and to reduce surface scuffing during deformation a sensible machine design would enable the riveting tool to freely rotate about its own axis. Such a machine would have a fixed axis of nutation, a precession motion of the tool axis and spin of the tool about its own axis. Hence (as shown in Figure 1) be a precession spin (PS) machine.

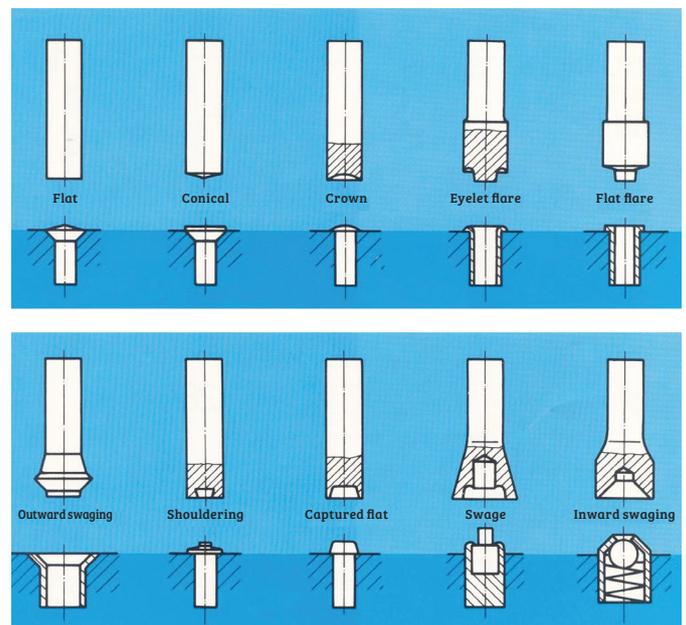
Table 1: Rotary riveting machine patents

Designer	Country Patent No.	Date	Kinematic Type							
			N	P	S	NP	NS	PS	NPS	
Briede	Germany 31944	1908		✓						
Snodgrass	USA 1089281	1913						✓		
Deshon	USA 2185939	1939							✓	
Bregen	USA 2739726	1954						✓		
Bodmer	USA 3173281	1962		✓						
Friedrich	USA 3440850	1967				✓				
Mink	USA 3618352	1969								✓
Berndt	UK 1276827	1969				✓				
Ramseier	USA 3620006	1970				✓				
	USA 3653243	1970				✓				
Mink	USA 3768289	1971				✓				
	USA 3779059	1971							✓	
Yoshikowa	UK 1434573	1973							✓	
Dragoun	UK 1490539	1973				✓				
	UK 1509779	1975				✓				

It should also be noted that all rotary riveting machines have their tool axis inclined to the machine/workpiece axis. This is the 'nutation' angle but a nutation (N) machine motion only occurs when the N angle is changed during the riveting operation.

The usefulness of rotary riveting is significantly enhanced by the way in which the incremental nature of the process can dramatically reduce the forming force required to achieve rivet closure. In this way very precise fits can be obtained for joining moving elements such as medical instruments and scissors. These can also be successfully used to capture brittle materials like ceramics. Figure 4 shows examples of the range of riveting operations that can be obtained using single or multiple rotary riveting heads.

Figure 4: Examples of rotary riveting operations (courtesy of Bracker Corp)



Rotary forging machines

Despite the human capacity to engage in intellectual self aggrandisement, no matter what physicists may say, the real world remains three dimensional. It is perhaps our greatest attribute that significant numbers of us see the same thing in different ways. So it is unsurprising that the simple notion of rotary riveting was also independently invented by others seeking to use the same incremental process but, in this case, on components three orders of magnitude bigger. Step forward, Edwin Elmer Slick (1868 – 1952) one of America’s true (but largely unknown) technological giants. As vice-president of the Midvale Steel Corporation, Johnstown, Pennsylvania – in a series of US patents dated 1907 to 1922 – he designed and then built four hot forging wheel mills capable of forging, from a 15 inch billet, a railway wheel in just 55 seconds as shown in Figure 5. The last of Slick’s mills was mothballed by Bethlehem Steel in 1982 and scrapped in 1988 having, with one major refurbishment in the 1950s, run continuously – producing wheel blanks, gears, sheeves and tyre moulds for over 60 years.

Figure 5: Slick mill spin machine (1907 – 1982)

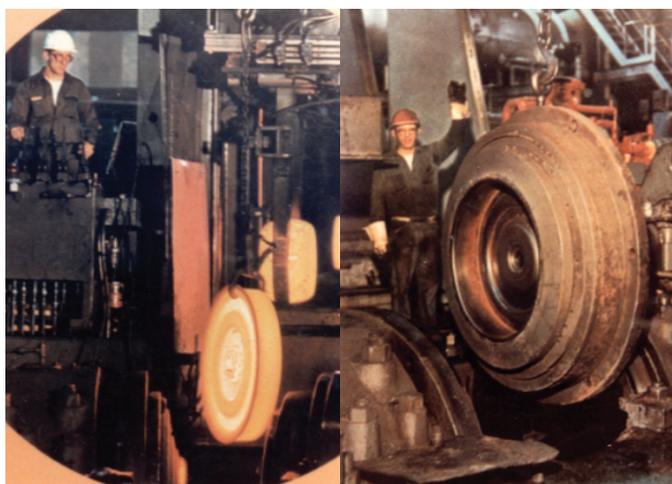


Table 2 shows the development of a number of rotary forging machine designs based on their kinematic motions (a comparison with Table 1 is interesting).

Table 2: Rotary forging machine kinematic designs

Designer	Country	Date	Kinematic Type							
			N	P	S	NP	NS	PS	NPS	
Slick	USA	1906-1922		✓	✓					
Massey HF	UK	1928		✓						
Silichev	USSR	1962-1974	✓	✓						
Marciniak	Poland	1967	✓	✓		✓				
Massey (B&S)	UK	1969		✓						
Qingjieng	China	1975		✓						
Wagner (SMS)	Germany	1980			✓					
Grzeskowiak	Poland	1981	✓							
Standring	UK	1982						✓		
Dyna East	USA	1983		✓						
Standring	UK	1988	✓							
Sumitomo	Japan	1988						✓		
MJC	USA	2013						✓		

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...selling extremely high-tech safety critical and precision made multi ‘component’ elements to a vehicle OEM for the price of a hamburger, hurt.”

It is also interesting that in 2011, Standard Steel was bought by Sumitomo Heavy Industries with the stated intention of introducing their ‘proprietary’ SIRD technology for the production of high speed rail wheels into North America. SIRD stands for Sumitomo Inclined Rotary Dishing and is based on the Slick wheel mill concept.

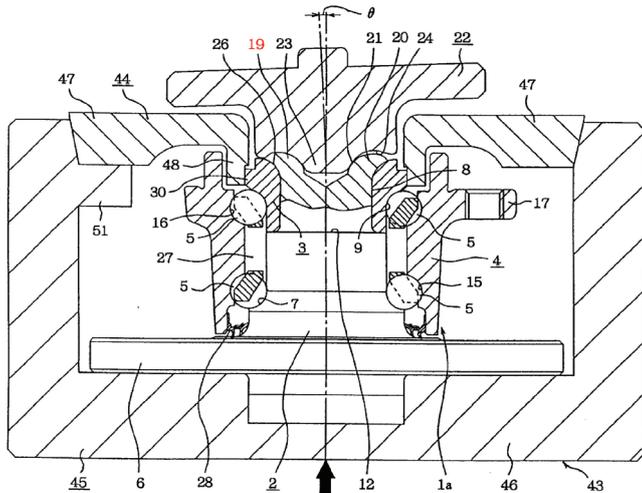
Clever fastening

The manufacturing ‘road map’ that Japanese industries created in the latter part of the 20th Century is one which all developing nations have sought to copy. Massive imbalance in trade goods led to the introduction of ‘transplants’. These brought in the idea of ‘local’ supply and the adaption (upgrading) of the transplant hosts, to improvements demanded by the Japanese OEMs. The reality behind the Japanese myth of manufacturing ‘master class’ was simplicity and common sense. Efficiency is achieved by minimising all effort whilst maximising output and to do this requires the integration of design for function, manufacture and assembly.

A classic example where the concepts of integrated design is made possible through the use of clever fastening is in the ubiquitous automotive wheel bearing. Those readers old enough to have run and maintained 20th Century vehicles, will well remember the time spent cleaning, regreasing and adjusting the wheel bearings every few thousand miles. Once completed, the wheel nut had to be tightened to apply a preload and then backed off before being locked in position.

For wheel bearing manufacturers, selling extremely high-tech safety critical and precision made multi ‘component’ elements to a vehicle OEM for the price of a hamburger, hurt. For the OEM faced with the inventory and costs of assembly, this was something they could well do without. Bring on the Wheel Hub Assembled Unit where a sealed for life integral assembly – consisting of hub, bearings and sensors – could all be captured at a set preload and rolling torque by a rotary forming process, which operated fully automatically, 24/7.

Figure 6: Rotary forming of wheel hub – item 19 using inclined tool 22.
US Patent 6524011, 25th February 2003



Bearing manufacturers could now sell a pre assembled, warranty free unit for significantly more than a simple bearing. Doing this could also improve the assembly line efficiency and reduce inventory/handling. Figure 6 shows one example of an assembled hub concept for which all automotive bearing manufacturers worldwide have their own designs. If a conventional forming operation were used to capture the bearing assembly, the force required would destroy the precision of the bearing elements. However, using an incremental rotary forming method reduces the force required by perhaps 30 times thus maintaining the integrity of the bearing elements.

A conservative estimate of the number of such wheel hub units produced each year must be around 200 million, which at between US\$50 to US\$100 for each unit will make the business worth between US\$10 billion – US\$20 billion (€9 billion – €18 billion). Not bad for what is in effect a big hollow rivet.

There are many similar examples where ‘smart’ forming methods can and are used extensively to make and/or capture other elements. The tabs on computer boxes and the balls on minimum friction tables are two. As any patent agent will report, there are always two elements to any patents. One is the ‘problem’ the other its ‘solution’.

Unfortunately most ‘problems’ that occur in manufacturing remain known only to the people who experience them. It is often

doubly unfortunate that those working in the area don’t have the breadth of experience to call upon to find a ‘solution’ – so circumvention is employed to get around it.

Problems and solutions

OK, manufacturing companies won’t share their problems. But, where countries have followed the Japanese manufacturing route map, they have invariably done it with expertise based on sometimes very clever counterfeiting of first world products. This has been achieved through rapid uptake (JIT), the flexibility of output (batch size production) and skill of the counterfeiters (although not necessarily in the ‘fit for service’ quality of the products). It has also proved to

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be the ‘practical’ base on which the national balance of payments surpluses have been generated when legitimate businesses emerge. This ‘copying culture’ is often second nature and why wouldn’t it be in some overpopulated, generally agriculturally dependent area, where little secrecy can be maintained. Of perhaps greater importance is the fact that such ‘hot-beds’ of industry in their programme of absorbing knowledge, also share it and in this way they ‘discover,’ ‘expose’ and often ‘reveal’ the problems that

mainstream OEM and tier 1 companies circumvent. Solve these and you move the goal posts, which means you can then bring your own product brands to the market.

There are of course ‘opportunities’ rather than ‘problems’ that are self evident to all in manufacturing. Lightweighting in transport is one. A reflection on what transport was like in 1906, 1916 and 1926

About the author

Peter Standring has spent many years working on rotary forging technology and in 1985 was awarded the UK Patent GB2104813B – titled ‘Rotary forging or riveting pub’ – on 30th May 1985. The concept of this invention was to have a machine in which the nutation (tilt) of the forging/riveting tool could be constantly changed under microprocessor control during a deformation cycle. Until that time, although many rotary forging machines had been designed and built around the world, none had the capability to vary the nutation axis in this way. A 50 tonne capacity machine was built to this design having a nutation capability of varying the axis from 0 to 45 degrees. It should be noted that until this time all commercial rotary forging machines operated with nutation angles between 0 and 5 degrees. In 2012 MJC Engineering, a specialist designer/builder of incremental metalforming machines, won an order from the Advanced Forming Research Centre (AFRC) –

a national Catapult Centre based in Glasgow, Scotland – to design and build a 200 tonne Nutation/Spin rotary forging machine using Peter’s concepts. This was successfully completed and installed in 2014 and is being used for R&D on high added value products [Ref 1, 2].

“MJC Engineering has a proven track record for conjuring quite remarkable complex shapes using novel IDP equipment it has designed and built,” explains Peter Standring. “Call MJC with a problem and it just might be able to provide a solution.”

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2. ‘Rotary Forging Celebrates a Century’, Carl Lorentzen, President, MJC Engineering, Published in Forge Magazine, 30th June 2014, www.forgemag.com/articles/84222-rotary-forging-celebrates-a-century?v=preview

will give some interesting consideration to our own time – in 2006 and 2017 – as to what 2026 could be like.

One of the major lightweighting technologies the automotive industry took on board two decades ago, and which has brought about a step change in engineering design, has been the Tube Hydroforming Process (THP). As all engineers know, weight for weight, all tubes are stronger than the same mass of solid metal. The reason is because the axis down the centre of a bar or tube is not stressed when loaded and is therefore termed the ‘neutral’ axis. The further away from the ‘neutral’ axis the material can be distributed, the more efficient its use. This distribution of material away from the ‘neutral’ axis in the USA is termed ‘the moment of inertia’ and in the UK ‘the second moment of area’.

For a circular section tube of uniform wall thickness (I), as it is often denoted, it is the same in any plane. For a square shaped tube, the two planes across the corners are stronger than across the flat surfaces. In the case of a rectangular tube, just like a long plastic rule loaded at each end, it will buckle across its shortest dimension.

Tubular constructions are often used in the design of automotive engine cradles, rear axles and space frames. CAE analysis of the in service application of such parts have revealed a requirement to have highly complex tube geometries, which can maximise the load bearing conditions of such structures. Hence the automotive industry’s significant interest in the THP and their own in-house investment in making it work. It is not overstating the case to say that TH has introduced a step change into automotive structural design.

A major ‘problem’ that TH introduced was how to fix/fasten often very irregular shaped tubes to a basically flat surface, say a bulkhead? A simple solution was to have separately cast ‘nodal’ elements of the tube geometry and simply to rivet/bond these to the ends of the TH parts.

Like most automotive solutions, this was expedient and although it will increase the vehicle mass, inventory, and the assembly time, it does provide an easy, ‘bolt-on’ solution.

The process of TH is simply that of blowing up a balloon inside a die cavity. The tube, sometimes in the case of a complex part, can be preformed (bent) to fit inside the die. The tube ends must be long enough so they can be fixed to a high pressure fluid source. When activated, the fluid fills the tube and as the internal pressure is increased, the tube expands to fill the cavity. The material is trimmed and the part finished off.

The high performance requirements of TH products naturally mean they are made from special purpose materials. Where complex shapes are produced, the sections of the tube will undergo

Figure 7: The flanging of non circular hydroformed tubes by incremental deformation



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different strains giving rise to the product having a range of different properties.

Figure 7 shows a section of one end of a well known SUV front engine beam into which a cast node is fixed prior to assembly in the car. The other end has a square section and the distance between them of ~1.1m follows a stretched and shallow ‘S’ form with the usual shape contours including ‘crumple’ zones. The part is hydroformed from a 108mm drawn tube of 2mm wall thickness. It is bent to its approximate ‘S’ form prior to being normalised and then hydroformed. Analysis of the formed part in eight regions have revealed variations, including in wall thickness due to processing of -6% to +22%, tensile strength from ~350 MPa to ~430 MPa and elongation from ~0% to ~23%. If a flange could be formed on the ends of the beam this could provide an integral bonded/riveted or spot welded solution giving rise to a simpler, lower cost joining solution.

Figure 7 also shows how it is possible to form a flange on the hydroformed tube end achieved in the ‘as received’ condition. The process used was a rotary forming/riveting approach using a forming force of under 5 tonnes. Despite the variation in material properties in the ‘as received’ hydroformed tube, no evidence of surface failure was found. This simple example demonstrates the significant advantages that an (IDP) approach to metalforming can have.

Further information on any of the aspects raised in the article can be obtained by contacting Industrial Metalforming Technologies (IMfT). +

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