by Peter Standring

Simple is best

What do We Know About Metalforming

Metalforming is not metallurgy. Sure, we must have metal if we are to form it but the ‘Science’ of metals is attested to by the knowledge gleaned from over a century of serious study.

In a similar way we can point to early empirical work to examine how metals behave when being subjected to various forces. This academic analysis of the stress and strain involved in obtaining permanent deformation has today been developed into numerical simulation packages.

Using these advanced systems, we can define the tooling, the workpiece geometry, dial in the material and its flow characteristics, the friction conditions and of course the tool motion(s) then press a key to see what happens and iterate if necessary.

Brilliant though these tools may be for predicting success and/or failure, the analysis they produce is limited by the computational technique the system uses and the accuracy of the data employed in the modelling. Hence, the fundamental need for the interpretive/intuitive skills of the person operating the package together with a knowledge of its limitations.

A young keyboard jockey may be quick to generate a result but a wiser older head could tell if it were sensible! If material manufacturers were to make the flow data of their products freely available to their customers everyone would benefit and metalforming simulation would become virtually universal. In the same way, if metalforming equipment manufacturers provided the kinematic data relating to their products in a form which could be used by the simulation packages, then two of the fundamental variables could be part of the drop down menu of every package.

Given that the term ‘Profession’ implies understanding and knowledge of a subject, then from the above, metalforming would appear to be doing well. Except that, from a ‘process’ point of view it is not!

Metalforming Processes

In the real world of 3D space, movement along or around the Cartesian axes of x, y and z will define the six degrees of freedom of which a body is capable of movement. It is also true that an object can only undergo three types of loading, those of tension, compression and shear. However, if a force of equal value, either tensile or compressive, is applied to a cube of ductile metal simultaneously along each of the three axes, then the resulting ‘hydrostatic’ stress will produce only elastic deformation in the compressive case, or eventual catastrophic failure in the tensile situation.

For a metal to deform in the ‘plastic’ range, the deviatoric (shear) stresses (stress difference between the loading in the x, y and z axes) must be different and the difference must achieve the value of yield stress for the metal. Mohr circles of stress diagrams, so often the bane of a struggling student’s life, are excellent at representing of how metalforming equipment can be used to best advantage. A simple example of rolling thin strip illustrates how the roll gap forces can be significantly reduced by the application of an additional transverse front/back tensile load. This is the science behind most incremental deformation processes where a workpiece can be formed in a sequence of stages using discrete blows or in a continuous manner. An obvious example is in closing a rivet by a hammering action or alternatively by causing the tool to roll or to orbit the forming head during closure.

Metalforming processes can be classified in exactly the same way as a metal cutting process if we consider the shape of the tool and the path it follows. In the use of a lathe, a forming operation would consist of a shaped tool being plunged into a workpiece to produce the ‘negative’ geometry of the tool. This would be equivalent to closing a rivet in a single operation or any single station open or closed die forming operation.

Alternatively, using the lathe analogy, a single point cutting tool can be used to ‘Generate’ a shape. Unlike the forming operation, this shape would bear no relationship to the geometry of the tool which created it. Again, this could be similar to a ‘rotary riveting’ operation or that of a spinning/flow forming process.

A single point screw cutting operation on a lathe would combine both ‘Forming’ and ‘Generating’ elements of the process much like a transverse rolling operation does (1).

A Learning Process

The old adage that ‘necessity is the Mother of invention’ is as true as any saying can be. The interest in incremental deformation processes came about when engineers in the early 20th century realised that creating ever bigger pieces of equipment was definitely not the best way forward. The recognition that by reducing the instantaneous area of contact between tool and workpiece, the required deformation could be achieved using significantly reduced force. This meant introducing more complex machine motions compared with the previous conventional uniaxial movement and thus became the goal to aim for.

Considerable progress in developing incremental deformation processes was made in the former Eastern European Bloc in the 1960's through to the demise of the USSR. In these 'command economies', the lack of a competitive market coupled with centralised manufacture and a well educated but very bored workforce, combined to develop a flowering of creative designs to improve the workpiece materials using the novel metalforming processes ideas they developed.

As global consciousness regarding manufacture in terms of both cost and its environmental effects becomes increasingly important, it is interesting to see many of these incremental deformation processes being employed globally by both the automotive and aerospace industries. Today, of course, all manufacturing processes use CNC which for multi axis, multi tool incremental metalforming means knowing how to program the machine first in order to obtain the desired outcome.

And here is the rub. Knowledge of how to program these sophisticated Shape Generation machines is 'proprietary information' owned by the companies which invested in acquiring it. Those who provide the simulation packages would clearly like the opportunity to invest in developing models for these processes. However, to do that, would require access to the 'proprietary information'! Being suppliers to the industry, the simulation developers would then want to sell their products to other companies competing in the same market.

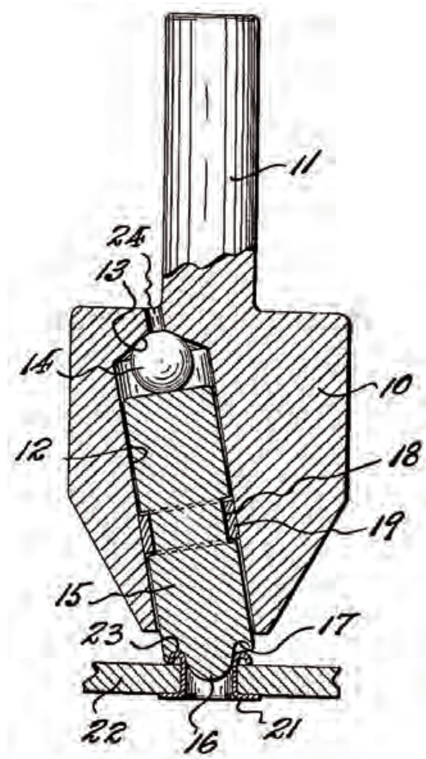

Figure 1. Bregen riveting tool (US Patent 2,739,726)

Since the dawn of time, the real chain of information exchange has been via the itinerant salesperson travelling from place to place. Much like bees transferring pollen, they sowed the seeds of new ideas where ever they went. It will be interesting to see how on-line ordering may influence, change or replace this age old transfer of knowledge?

Incremental Deformation Applied to Fastening

Patent Offices are bursting with old and new novel ideas for equipment to fasten metal components together, or to create the shape(s) needed to do this. Three examples will illustrate how a simple and sensible idea can be developed, often through a desire to obtain a 'new' patent or to display the 'engineering' virtuosity of the designer. However, as will be shown, without a fundamental understanding of the process, each iteration can move further away from 'good practice.'

Figure 1 shows a simple design of what is commonly termed a rotary or orbital riveting system. In this case the peen tool shown is for setting hollow rivets but it could be made with an end shape which could close other rivet types. The inclined axis of the peen within the tool holder causes the peen to rotate about the spinning axis of the head when the tool holder rotates. The ball acts as a thrust race and the peen can rotate about its own axis caused by the friction generated at the tool/work contact. It should be noted that the design shown in Figure 1 is one of very many, the first possibly being attributed to Briede in 1908 (2).

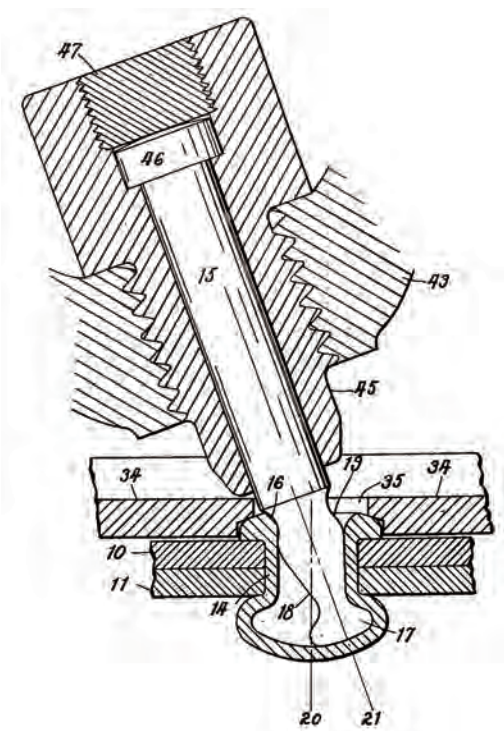

Figure 2. Deshon et. al. riveting device (US Patent 2,185,939)

Figure 2 shows a French idea which the designers claimed could be used in the aircraft industry. The principle is basically the same as in the first situation except in this case, the peen holder begins the action in the vertical position and is caused to tilt its axis during the process to the position shown. Clearly, this operation must be reversed in order to remove the peen and this is achieved by springs.

The third example, **Figure 3**, which to this Author appears to be a condition of creative engineering mayhem, illustrates a design which basically repeats the form of the previous two. However, in this case, the peen holder body, in addition to rotating about its own axis, can also be caused to rotate by shaft 21 driving pinion gears 65, 66 and 67.

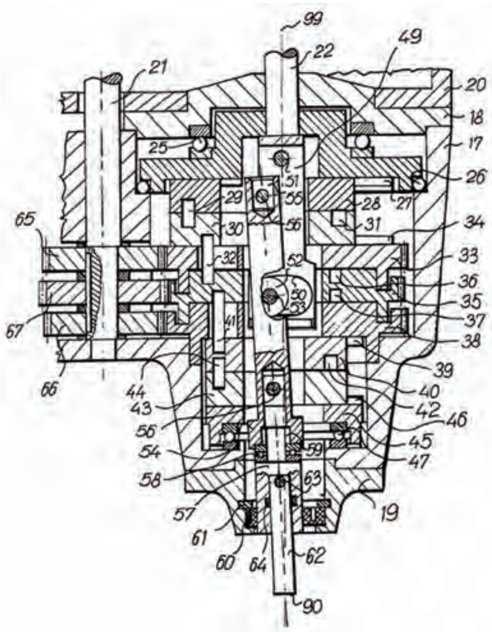

Figure 3. Dragoun riveting system (US Patent 3, 990, 285)

The three methods selected from many examples represent how by thoughtful analysis, engineers might question, “What it is we are trying to achieve?”

Take a pen and hold it vertically between your two forefingers. This represents the axis of the peen. Now, as in **Figure 1**, move the top finger to the right or left whilst keeping the bottom finger stationary. This represents the peen axis in the inclined position. Maintaining the bottom finger stationary, rotate the top finger around the imaginary axis which extends upwards. This action represents the movement of the tool axis during a riveting operation; hence, the rotary or orbital motion.

It should be noted that the pivot point (the intersection of the two axes – vertical and inclined) lies on the surface of the bottom finger and the pen. This factor is crucially important in all peen designs. Simple geometric analysis will show that since the surfaces of the deforming rivet and the peen are different, then the 2π relationship around their respective axes at virtually any contact point, will also be different. This means that the angular velocity of the peen around its own axis driven by friction at the rivet interface could be greater or less than that of the rivet about its axis, which is of course, zero. Hence, in this embodiment there is a need for the peen to rotate about its own axis to reduce surface scuffing.

In **Figure 2**, the pivot point is shown to be on a horizontal plane coincident with the top of the material being riveted. Returning to the pen model, this is the same as holding the pen body between the thumb and forefinger of the bottom hand with the pen in the vertical position. Now, it is necessary to rotate the top finger around the imaginary vertical axis whilst simultaneously moving to the right or left creating a spiral movement.

Clearly, when this takes place, a mirror image of the pen motion is created below the pivot point of the lower finger and thumb. Also, whilst doing this, it will be noticed that the body of the pen will rotate about its own axis in a direction opposite to that of the top finger rotation. This indicates the frictional effect mentioned previously.

Besides solving the problem of causing the peen axis to tilt under controlled conditions during the process, the difference in geometry between the peen/rivet contact above and below the pivot point will result in serious surface scuffing and pick up. In addition, the peen design does not appear to take into consideration any requirement for rotation about its own axis or possible means of lubrication as seen in **Figure 1**.

It is acknowledged by this Author that the design in **Figure 3** is extreme and was indeed simplified by the designer in a further Patent taken out a year later.

Returning to the pen model, in this third example, which is similar to the Marciniak design for an orbital forging machine, (3) the pen is held between the two forefingers in a vertical position. By fixing the previously mentioned tool holder gears to rotate in the same direction at the same speed it is possible to get the peen axis to rotate about the vertical axis as in **Figure 1**. Driving the gears in opposite directions at the same speed will make the peen axis rock from side to side as will happen if the lower finger supporting the pen is stationary and the top is moved in a plane from right to left and back.

By selecting different gear ratios, this design can cause the peen axis to move in and out in a continuous spiral motion or in a petal movement by having more rock than roll or vice versa! In the embodiment shown, the peen tool is fixed from rotation about its own axis. The effect of the peen gyrations on the rivet as it is being formed can be speculated by considering the constantly changing size, shape and position of the tool/workpiece contact. Simulating such a contact is challenging with the results demonstrating both the positive and negative consequences produced by the various motions.

Conclusion

All engineers should be aware that good design achieves functional simplicity through understanding. Time spent defining just what the real problem is will be rewarded by the knowledge that the solution obtained is justified. The simplicity of the solution should, in itself, confirm that the work was worth doing in the first place.

References

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2. O. Briede, German Patent No. 31944, 1908
3. Z. Marciniak, US Patent No. 3, 523, 442, 1970