

# **AN APPARATUS AND METHOD FOR FORMING A PERFORATED TUBE**

## **Technical Field**

The present disclosure relates to the formation of perforated tubes. In particular, the present disclosure relates to an apparatus and method for forming a perforated tube, and a perforated tube formed by that apparatus and method.

## **Background**

Perforated tubes generally comprise a cylindrical metal body with a pattern of through-holes or perforations formed in the wall of the body. When used in motorcycle and car exhaust systems, the perforations permit passage of gasses from inside the tube to outside the tube, and can also muffle exhaust noise.

It is understood to be difficult to perforate a cylindrical body since any pressure applied to form perforations must necessarily be applied to a rounded surface. Thus the tube often slips so that the location of the perforations cannot be consistently controlled. In addition, the force required to form a perforation (e.g. by punching) creates stress in the tube that exceeds the yield strength of the material from which the tube is formed. Thus the cylindrical shape of a tube often deforms as it is being perforated.

For these reasons, perforated tubes are typically formed by perforating a flat metal sheet, subsequently rolling the sheet and the welding opposite edges of the rolled sheet together. In order to weld the opposite edges together, a clean edge (i.e. without notches or perforations) must be present on both sides of the weld. Thus perforated tubes typically cannot be perforated consistently around the entire tube wall.

Moreover, it is not possible to form a perforated tube with irregular shape (e.g. more than one diameter) using the prior art, since the flat sheet, when rolled will have one diameter. Any variations from that diameter will require stretching of the tube, in a process known as “swaging”, in which a tool is force into the tube to enlarge (or in some cases, reduce) the diameter of the tube. Since the perforations weekend the tube, the perforations preferentially distort before the tube is swaged. Thus the tube buckles, folds and distorts about the perforations. The alternative is to weld two perforated tubes together with a fluted section between them, but this is both messy and requires a large number of rolling, welding and perforating steps to be performed.

It is desirable that there be provided an apparatus or method for forming a perforated tube that avoids one or more of the above limitations, or at least provides a useful alternative.

5     **Summary**

In accordance with the present disclosure there is provided an apparatus for forming a perforated tube, comprising:

        a main support; and

        a die assembly mounted to the main support and comprising two opposed die  
10     members, the two opposed die members including a first die member and a second die member, the first die member having an axis and being configured to be at least partially inserted into a tube, the tube comprising a swaged section, wherein the die assembly comprises a first die support for pivotally supporting the first die member on the main support;

15     wherein the apparatus is operable to perform a repetitive punching operation, by bringing the two opposed die members together, to punch at least one perforation in the tube, and subsequently moving the two die members apart, the apparatus further comprising:

        a rotation assembly comprising a rotation member rotationally mounted to the main  
20     support, the rotation member rotating the tube, by a predetermined amount, between successive punching operations to punch a predetermined pattern of perforations in the tube.

In accordance with the present disclosure there is also provided a method for forming  
25     a perforated tube, comprising:

        forming a swaged section in a tube;

        at least partially inserting a first die member into the tube;

        performing a repetitive punching operation, by bringing the first die member  
30     together with a second die member to punch at least one perforation in the tube, and subsequently moving the first die member and second die member apart; and

        rotating the tube, by a predetermined amount, between successive punching  
operations to punch a predetermined pattern of perforations in the tube, wherein the first die member and the second die member forms part of a die assembly mounted on a main support, the die assembly comprising a first die support for pivotally  
35     supporting the first die member on the main support.

In accordance with the present disclosure there is further provided a perforated tube formed by the apparatus described above, the tube comprising a plurality of  
5 perforations arranged such that any line drawn longitudinally of the tube will intersect at least one perforation.

In accordance with the present disclosure there is further provided a perforated tube formed by using the method described above, the tube comprising a plurality of

perforations arranged such that any line drawn longitudinally of the tube will intersect at least one perforation.

In the present context, the term “tube” and similar should be taken to mean any closed-cross section, elongate, hollow body. The cross-section of the tube may be cylindrical or square, but may also have any other desired cross-sectional shape, regular or irregular.

#### **Brief description of the drawings**

Some embodiments of the method and product will now be described, by way of non-limiting example only, with reference to the accompanying drawings in which:

Figure 1A shows a apparatus for forming a perforated tube, in accordance with present teachings;

Figure 1B is a partial close-up view of a rotation assembly in accordance with present teachings;

Figure 1C illustrates a rack and pinion arrangement that can be used in place of the wheel and indexer arrangement of Figure 1B;

Figure 1D illustrates an alternative indexer arrangement to that shown in Figure 1B;

Figure 1E shows an alternative arrangement for defining indexing positions of the wheel shown in Figure 1A;

Figure 2A shows a schematic view of the apparatus of Figure 1;

Figure 2B illustrates rotation of a first die member in accordance with present teachings, on a first die support, between a loading condition and a punching condition;

Figure 3 is an end view of the apparatus shown in Figure 2A;

Figures 4A and 5A each show a first die member in accordance with present teachings, and tube with perforations formed using that die member;

Figure 4B and 5B each show an indexing wheel and pitch guide in accordance with present teachings;

Figure 6 shows a perforate tube in accordance with present teachings, having two sets of perforations, the sets of perforations having respectively angular offsets;

Figures 7 and 8 show first die members in accordance with present teachings; and

Figures 9 and 10 show a prior art tube and a tube formed in accordance with present teachings.

#### Detailed description

Figure 1A shows an apparatus 100 for forming a perforated tube. The apparatus is operable to perform a repetitive punching operation to punch a predetermined pattern of perforations in a tube 102, to thereby form a perforated tube.

The apparatus 100 includes a main support 104 and a die assembly 106 mounted to the main support 104. The die assembly 106 comprises two opposed die members 108, 110, the two opposed die members 108, 110 including a first die member 108 and a second die member 110.

The punching operation is performed by bringing the two opposed die members 108, 110 together, to punch at least one perforation in the tube 102, and subsequently moving the two die members 108, 110 apart. In general, a single punching operation will result in multiple perforations being concurrently formed in the tube 102.

The apparatus 100 further comprises a rotation assembly 112. The rotation assembly 112 includes a rotation member 114 rotationally mounted to the main support 104. The rotation member 114 rotates the tube 102, by a predetermined amount, between successive punching operations. In so doing, the successive punching operations result in perforations being formed at different positions in the wall of the tube 102, resulting in a pattern of perforations being progressively formed.

In general, the tube 102 will have an axis and the pattern of perforations will be formed generally symmetrically about that axis. Thus the first die member 108 is elongate and includes an axis X, and is configured to be at least partially inserted into the tube 102. During rotation of the tube 102, the rotation assembly 112 rotate the tube

102 about the axis of the first die member 108 and thus about the axis of the tube 102 itself.

The main support 104, in effect, forms the body of the apparatus 100. Components of the apparatus 100 that are internal to a housing 116 of the main support 104, such as drive components (e.g. motor and pneumatics), but their usage will be understood by the skilled person.

During punching operations, the two die members 108, 110 press together. In order to form perforations, one of the two opposed die members 108, 110 comprises at least one punch, and the other of the two opposed die members 108, 110 comprises a corresponding aperture for each punch. In the present embodiment, the second die member 110 comprises three punches 118, though any number and arrangement may be provided as necessary. Similarly, the first die member 108 comprises three apertures 120, each aperture 120 being located to receive a respective punch 118 during punching operations.

The punches 118 have a circular cross-section, though any cross-section may be used as appropriate in order to achieve the desired shape of perforations in the tube 102. Punches 118 with a rounded cross-section are generally desired as the absence of sharp corners comparatively increases the life of the punch 118 and reduces stress concentrations in the perforation tube.

The apertures 120 have a cross-section that cooperates with that of the punches 118. In particular, where a punch 118 has a circular cross-section the corresponding aperture 120 will have a similar cross-section but with a slightly greater diameter so as to be able to receive the end of the punch 118 as a respective perforation is punched into the tube 102. During punching operations the punches 118 bear against the tube 102 and each punch 118 presses a slug – the portion of the wall of the tube 102 punched out by the punch 118 – into the corresponding aperture 120 in the first die member 108.

If the slugs are not ejected from the apertures 120 then they would collect and ultimately clog the apertures 120. Accordingly, the first die member 108 comprises a slug collection recess 122 (shown in broken lines) for collecting slugs punched from the tube 102 as a predetermined pattern of perforations is punched in the tube 102. The slug collection recess 122 comprises an elongate through-hole extending axially

of the first die member 108. The apertures 120 extend from the outer surface of the first die member 108 and terminate in the slug collection recess 122. In Figure 1A, the opening 124 for each aperture 120 is visible, and the extension 126 of the respective aperture 120 from that opening 124 down into the slug collection recess 122 is shown in broken lines.

In general, the extension 126 will have the same diameter as the opening 124. However, in some instance the extension 126 may have a slightly large diameter than the opening 124 so that any slugs of a size and shape to be received through the respective opening 124 will be necessarily smaller than the maximum size that will fall through the extension 126 into the slug collection recess 122, thus avoiding slugs becoming caught. For example, the angle subtended between at least part of the sidewall of the extension 126 and the flat land (i.e. outer surface) extending from the respective opening 124 of the first die member 108 may be between 82° and 87°. In other words, relative to a line extending perpendicularly inwardly of the first die member 108 from the opening 124, at least part of the sidewall of the extension 126 may extend outwardly at an angle of between 3° and 8°. The widening diameter of the extension 126 may commence at some point inwardly, and spaced from, the opening 124.

Similarly, the slug collection recess 122 may have substantially circular in cross-section. The diameter of the slug collection recess 122 may be larger than that of the opening 126 and thus any slug capable of fitting through the opening 126 will be too small to be caught in the slug collection recess 122.

The slug collection recess 122 extends from one end 128 of the first die member 108 to the opposite end 130. It will be appreciated, however, that the slug collection recess 122 may only extend part way along the first die member 108. There may also be more than one slug collection recess 122. The size and number of slug collection recesses, and whether they extend the full distance, or only part of the distance, between the opposed ends 128, 130 of the first die member 108 is not critical, provided that each aperture is connected to a slug collection recess and that the respective slug collection recess can be emptied (e.g. using compressed air) of any slugs that collect within it.

In the present embodiment, the apparatus 100 is operable to perform a repetitive punching operation by bringing the second die member 110 down upon the first die

member 108, thereby capturing the tube 102 between the two die members 108, 110 during each punching operation. To achieve this, the second die member 110 is driven down towards the first die member 108 by a drive – as such, the apparatus may comprise a power press. The drive presently comprises a plurality of pneumatic  
5 pistons 132, 134 that extend and retract to move the second die member 110 towards and away from the first die member 108 respectively. Thus the apparatus 100 is movable between an open condition as shown in Figure 1A, in which the punches 118 are not in contact with the tube 102, and a closed condition in which the punches are in contact with the tube 102.

10 The closed condition of the apparatus 100 is schematically represented by partial apparatus 200 in Figure 2A. With reference to Figure 2A, punches 202, 204 are shown penetrating through the tube 206. Each of the punches 202, 204 is configured to form a respective perforation in the tube 206 during each punching operation. Moreover,  
15 punches 202 and 204 are of different sizes and are located at different areas on the tube 206 such that, during punching, holes of multiple different diameters may be concurrently formed. It will be appreciated that in this instance, where both punches 202, 204 are used for each punching operation, the centre-to-centre angular offset (i.e. the angle between lines extending from the axis of the tube through the centre of each  
20 of two perforations) of successive perforations formed by punch 202 will be the same as those formed by punch 204. Where different angular offsets are desired a different process is used as discussed with reference to Figures 7 and 8.

The second die member 232 comprises a punch holder 208 for holding the punches  
25 202, 204. The punch holder 208 includes a through-hole 210 for a respective punch 202, 204. Each through-hole 210 extends from a rear surface 212 to a front surface 214 of the punch holder 208. Each through-hole 210 includes a seat 216 extending inwardly from the rear face 212. Each punch 202, 204 includes a corresponding lug 218 at its rear end (the respective punch 202, 204 using its forward end to punch  
30 through the tube 206). The lug 218 is received in the seat 216 and prevents the punch 202, 204 from sliding out of the through-hole in the direction of the tube 206 when the apparatus 200 is in an open condition.

The punches 202, 204 are thus inserted through from the back of the punch holder  
35 208 through the rear surface 212. The second die member 206 also includes a backing plate 220 to prevent the punch 202, 204 from becoming unseated from within the punch holder 208 during punching operations. The punch holder 208 and backing

plate 220 may be secured together using any appropriate means, such as bolts (not shown). Similarly, both the punch holder 208 and backing plate 220 are supported by an upper die shoe 221 of the second die member 232 and may be bolted thereto, or otherwise attached in any appropriate manner.

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Figure 2A also shows a stripper 222, comprising a stripper plate 224 and stripper backing plate 226. The stripper 222 is moveable with the second die member 232 – the backing plate 220 in particular – to contact the tube 206 to thereby maintain the position or alignment of the tube as the two opposed die members 230, 232 are brought together. Similarly, the stripper 222 maintains a position of the tube 206 during removal of the punches 202, 204 from the tube 206.

The stripper 222 includes a longitudinal central void (not shown) through which the punches 202, 204 can access the tube 206. The stripper 222 is biased, presently by multiple springs 228, towards the tube 206. The stripper 222 applies pressure to the tube 206 to ensure it is aligned with the punches 202, 204 during punching operations. The stripper 222 is also the last component to disengage the tube 206 – in other words, to cease being in contact with the tube 206 – when the first and second die member 230, 232 are moved apart when the apparatus 200 returns to the open condition. Thus the stripper 222 also ensures that withdrawal of the punches 202, 204 from the tube 206 does not pull the tube 206 out of alignment with the rotation assembly 234.

The stripper 222 is shown to be attached to the backing plate 220 by biasing member 228. However, the stripper 222 may be attached to any appropriate part of the apparatus 200.

The stripper 222 is shown partially overlapping the tube 206. This is because the tube 206 is the present embodiment has a circular cross-section, with the punches 202, 204 penetrating around the top of the tube 206 (with respect to the view shown in Figure 2A) and thus parts of the stripper 222 being located further around the circumference of the tube 206 on either side of the location at which the tube 206 is punched.

As shown in Figure 3, the stripper 222 includes an arcuate notch 250 at either end. The arcuate notch 250 is shape to cooperate with the first die member 230, to ensure close contact with the first die member 230. It will be appreciated that the stripper

plate 224 may instead be formed from a resilient material, such that it deforms to conform to the shape of the first die member 230.

The operation and attachment of strippers to die pairs (e.g. a pairing of a first die member and a second die member, though in the context of flat plate pressing) will be generally understood in the art and need not be described in greater detail herein.

The stripper 222 forms part of a guide assembly (generally designated 236 in Figure 2A) of the die assembly. The guide assembly 236 guides movement of the two opposed die members 230, 232 as they are brought together. In addition to, or as an alternative to, the stripper 222, the guide assembly 236 comprises a plurality of pilot pins 238, 240, 242 receivable in corresponding pilot pin apertures 244, 246, 248 as the two opposed die members 230, 232 are brought together. The pilot pin apertures 244, 246, 248 extend through the first die member 230 such that the pilot pins fix the position and alignment of the first die member 230 as the second die member 232 moves toward it.

The pilot pins 238, 240, 242 are each provided with a lug and are receivable in a through-hole in the punch holder as per the punches 202, 204, and are held in those through-holes by the backing plate 220.

It will be appreciated that one or more guide pins may be used as appropriate, and that the use of three guide pins in the present embodiment is for illustrative purposes only. Where a single pilot pin is provided, the corresponding aperture for that pin should be located towards an end of the first die member 230 – with reference to Figure 1A, end 128 is preferred since end 130 is already supported by a first die support 136. Where the guide assembly comprises two pilot pins, it can be useful for those pilot pins to each be receivable in a corresponding pilot pin aperture located toward respectively opposite ends of the first die member.

The first die member 230 is supported in a position to facilitate perforation of the tube 206. Die supports are provided to support the first die member 230 in this position. In particular, the die assembly includes a first die support 252 for pivotally supporting the first die member 230 on the main support.

The first die support 252 is upstanding on a lower die shoe 254 and has a groove cut in its upper end, in which the first die member 230 is located. The first die member 230 is connected to the first die support 252 by a hinge. The hinge comprises a pin 256

extending through the upper end of the first die support 252, and through the first die member 230, to fix the first die member 230 in the groove of the first die support 252.

With reference to Figure 2B, the first die member 230 pivots about the hinge (or pin 256) between a loading condition (ref 258 – shown in solid lines), in which a perforated tube can be removed from the first die member 230 and the first die member 230 can be received in a further tube, and a punching condition (ref 260 – shown in broken lines), in which the first die member 230 is in a position in which the further tube is retained over the first die member 230.

To ensure the first die member 230 does not bend away from the second die member 232 during punching operations, the die assembly also includes a second die support 262 as shown in Figures 2 and 3. The first die support 252 and second die support 262 support portions of the first die member 230 at or towards opposite ends of the tube (i.e. towards opposite ends of the first die member 230) during punching operations.

As shown in Figure 3, the second die support 262 has an upper surface 264 configured to receive the first die member 230. In particular, the upper surface 264 forms a groove that receives the end of the first die member 230. When in the punching condition as shown, the first die member 230 is connected to the second die support 262. That connection is effected by a removable pin 266 extending, in use, through the upper end of the second die support 262, and through the first die member 230, to fix the first die member 230 against the upper surface 264 of the second die support 262. Thus the first die member 230 is in contact with the second die support 262 when in the punching condition and moved out of contact with the second die support 262 when in the loading condition. It will be appreciated that many other mechanisms for securing the first die member 230 to the second die support 262 may be used, and all such mechanisms and variations thereto are intended to fall within the scope of the present disclosure.

Similarly, the second die support 262 may be movably connected to the lower die shoe 254 so as to move away from the first die member 230 to enable a tube to be loaded onto, unloaded from, the first die member 230. In this configuration, the first die member 230 may be integrally formed, or otherwise rigidly fixed to, the first die support 252.

As a result of the first die member 230 being fixed to the first and second die supports 252, 262 when in the punching condition, the tube is retained, in use, between the first die support 252 and a second die support 262. By fixing the position of spaced portions of the first die member 230, the spaced portions in the present instance being towards opposite ends of the first die member 230, the first die support 252 and second die support 262 maintain the first die member 230 in alignment with the second die member 232 during punching operations.

In order to punch successive sets of perforations into the tube, the tube is rotated by a rotation assembly. In the embodiment shown in Figure 1A, the rotation assembly 112 includes a rotation member 114 and an indexer 138. That rotation member 114 is in the form of an indexing wheel that has an index position for each punching operation to be performed on the tube. Between successive punching operations the indexer 116 rotates the indexing wheel 114, with the tube, to successive indexing positions.

The indexing wheel is received around the first die member 108, such that the axis X of the first die member 108 is coincident with that of the indexing wheel. Similarly, the indexing wheel is movable, with the first die member 108, between the loading condition and punching condition. While the indexing wheel may be fixed to an axle, the present indexing wheel is freely rotatable about the first die member 108. Since the tube 102 is connected to the indexing wheel as discussed with reference to Figures 4A, 4B and 4C, it is rotated with the indexing wheel between successive indexing positions for punching by the second die member 110.

With reference to Figure 1B, the indexer 138 engages the wheel 114 and rotates the wheel 114 from one indexing position to the next indexing position, before disengaging from the wheel 114. To ensure the wheel 114 does not over-rotate (i.e. rotate past the next indexing position) or under-rotate (i.e. not rotate all the way to the next indexing position, or not rotate past back from that position after disengagement from the indexer 138), the rotation assembly also includes a stop 142.

The indexer 138, shown in Figure 1B, comprises a body 144 supporting a resilient element 146. The body 144 is raised and lowered at the same time as the second die member 110. Thus, raising and lowered of the indexer 138 may be effected by the drive (e.g. pneumatic pistons 132, 134) discussed in relation to Figure 1A.

The wheel 114 indexing wheel comprises a sawtooth peripheral edge 154 having multiple teeth 156. The wheel further comprises a plurality of engagement elements, presently embodied by lugs 148, by which the indexer 138 engages the wheel 114 to move the wheel 114 between successive indexing positions. There is one engagement  
5 element for each tooth of the sawtooth peripheral edge. In operation, after punching perforations into the tube, the punches 118 are retracted as the second die member 110 is retracted. Similarly, the indexer 138 is drawn upwardly in the direction of arrow Y'. During this movement the resilient element 146 engages a lug 148 and rotates the wheel 114 in the direction of arrow Z'.

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Notably, the force applied by surface 152 of the wheel 114 is sufficient to bend the leaf spring, stop 142, away from the position shown and in the direction of arrow W. This is because the component of the force applied by one tooth 158 – and, in particular, surface 152 of that tooth – to the stop 142 in a direction transverse to the direction of  
15 extension of the stop 142 (i.e. tangential to the direction of arrow W) is greater than the force required to bend the stop 142. Thus the resilient member 146 applies sufficient force to lug 148 to ensure surface 152 can bend the stop 142, thereby permitting the wheel 114 to rotate.

20 Various other options for holding the wheel 114 in position may be used. For example, a friction plate (shown in broken lines and designated 166 in Figure 1A) may be disposed between the wheel 114 and support 136. The friction plate 166 is fixed to one of the wheel 114 and support 136 and bears against the other of the wheel 114 and support 136 such that the wheel 114 cannot freely rotate relative to the support 136  
25 about the first die member 108.

A further alternative, shown in Figure 1E, would be to replace the stop 142 with a spring loaded guide 184. The guide 184 comprises a sprung stop 188 that is biased in the direction of the wheel 186 and the wheel includes a series of spaced recesses 190  
30 that conform to the shape of the end of the stop 188. The recesses 190 are located at positions of the wheel 186 that correspond with the indexing positions, such that when the wheel 186 reaches an indexing position the stop 188 will extend into the recess 190 and prevent free rotation of the wheel 186 away from the indexing position. This arrangement is less preferable to the stop 142 arrangement due to the  
35 mechanical complexity of the arrangement of Figure 1E.

With further reference to Figure 1B, shortly after the surface 152 moves past stop 142, the stop 142 returns to the position shown, but is now received between tooth 158 and its neighbouring tooth 160. Since the resilient member 146 is no longer causing the wheel 114 to rotate, the stop 142 substantially prevents the wheel 142 from further rotating.

When the indexer 138, along with the second die member 110, commences the next punching operation, they are lowered towards the first die member 108. In this case, the resilient member 146 again contacts a lug 148. However, the force applied by the tooth of the wheel 114 to the stop 142 is not sufficient to bend the stop 142, away from the position shown, in the direction of arrow W'. This is because the stop 142 is angled to form an over-centre device (e.g. a ratchet) with the wheel 114. To illustrate this arrangement, with reference to Figure 1B, as the indexer 138 is lowered in the direction of arrow Y, the resilient member bears against tooth 150. In so doing, surface 162 of tooth 164 bears against stop 142 as the wheel attempts to rotate in the direction of arrow Z. However, the contact angle between surface 162 and stop 142 is selected such that there is less transverse, or lateral, force applied by the surface 162 to the stop 142 than that applied by surface 152 when the wheel 114 is attempting to rotate in direction Z'. The lesser force is insufficient to bend the stop 142 away from the position shown, in the direction of arrow W'. Thus the resilient member flexes around the lug 150 without moving the wheel 114 back to the previous indexing position.

Various alternative embodiments for the indexer may also be used. One such alternative indexer 168 is illustrated in Figure 1D. In indexer 168 the resilient element has been replaced with a rigid, hinged tab 170. The tab 170 is hinged to a rigid stop 172 by a hinge 178. The tab 170 has a flat rear surface 174 that rests against a flat leading surface 176 of the stop 172. The hinge 178 is located at the top of the rear surface 174. As such, when the indexer 168 is moved upwardly in the direction of arrow C, and the tab 170 comes into contact with a lug 148, the flat rear surface 174 and flat leading surface 176 are pushed against each other. This prevents the tab 170 from pivoting about the hinge 178, since the hinge 178 is at the top of the rear surface 174 the tab 170. The tab 170 thus engages the lug 148 and turns the wheel 114. Conversely, when the indexer 168 is moved downwardly in the direction of arrow C', and the tab 170 comes into contact with a lug 148, the tab 170 pivots about the hinge 178 (e.g. to position 180 shown in broken lines) thus passing by the lug 148 without applying sufficient force to the lug 148 to rotate the wheel 114. In practice, the force

applied by the tab 170 to the lug 148 with downward motion of the indexer 168 will be practically zero.

In addition, the wheel 114 may be rotated using another means (e.g. a servomotor), or  
5 may be replaced with a differently shaped body by which to rotate the tube 106. For  
example, wheel 114 may be replaced by wheel 180 as shown in Figure 1C, that is  
rotated using a rack and pinion type of arrangement. In such an arrangement, the  
pinion (i.e. wheel 180) is rotated by longitudinal movement of a rack 182 in a generally  
10 known manner. The rack 182 may move in a single direction, or with reciprocal  
motion. For reciprocal motion, the tube may be replaced at both extremities of travel  
so that one reciprocal cycle of the rack 182 results in the creation of two perforated  
tubes. For example, movement of the rack 182 in direction A would induced rotation  
of pinion 180 in direction A', and induce a corresponding rotation in a tube. Upon one  
15 full rotation of the tube, all perforations are formed. Thus when the rack 182 has  
reached its end of travel in the direction A, the tube is replaced for a fresh (i.e.  
unperforated) tube and the rack 182 in direction B, inducing rotation in direction B'  
with a corresponding rotation in the fresh tube, thereby facilitating perforation of the  
fresh tube. Rack and pinion motion will be understood by the skilled person and need  
not be described in further detail herein.

20 For precise location of perforations on the tube, or where very small spacing between  
neighbouring perforations is desired, stop 142 may not maintain the location of the  
wheel 114 in a sufficiently exact position. With reference to Figure 4B, to improve the  
accuracy of the location of the indexing wheel 400 in each indexing position, the  
25 rotation assembly further comprises a pitch guide 408 (see also ref 140 in Figure 1A).  
The pitch guide 408 is movable into contact with the indexing wheel 400, in the  
direction of arrow V, to maintain the indexing wheel 400 in an indexing position during  
punching of holes in the tube, and movable out of contact with the indexing wheel, in  
the direction of arrow V', to permit rotation of the indexing wheel to another of the  
30 indexing positions. The pitch guide 408 may be spring loaded and fitted at any  
appropriate position for movement with the second die member (e.g. on the punch  
holder as described in relation to Figure 1A).

During a punching operation, the pitch guide 408 moves downwardly in the direction  
35 of arrow V, along with the second die member 110, and into contact with the indexing  
wheel 400. The end 410 of the pitch guide 408 is shaped to be a negative of the shape  
of the tooth 412 with which it comes into contact. In particular, the end 410 includes a

triangular notch for receiving a tooth of the sawtooth peripheral edge to maintain the indexing wheel in the respective indexing position. Each of the points 414, 416, 418 of the triangular notch provides a separate point of contact with the tooth 412 and thus the end can maintain the wheel 400 in an indexing position with high accuracy. After perforations are punched into the tube, the pitch guide 408 is retracted, along with the second die member (not shown), to permit the wheel 400 to rotate to the next indexing position.

The sawtooth arrangement shown in Figure 4B can be used for very tight tolerances between perforations – in other words, when small spacing is desired between perforations and thus the perforations must be positioned with a high degree of accuracy.

The indexing wheel may be shaped in any desired manner, and retained in position by any desired mechanism, to ensure proper location of the wheel in the various indexing positions and, similarly, accurate location of the perforations on the tube. For example, with reference to Figure 5B the indexing wheel 500 comprises a peripheral edge 502 having a plurality of spaced notches 504. The pitch guide 506 may again have an end shaped to be the negative of one of the notches 504 – for example, where the notches are triangular in shape the pitch guide 506 may have a triangular end. However, in the present instance, even though the notches 504 are triangular, the pitch guide 506 has a rounded end 508. The rounded end 508 is still receivable in a respective one of the triangular notches 504 to maintain the indexing wheel 500 in the desired indexing position, but the degree of accuracy of location may be lower than that afforded by the arrangement of Figure 4B.

It will be noted from Figures 4B and 5B that the wheel 400, 500 comprises a keyed central aperture 420, 510. With reference to Figures 4A and 5A, the first die member 402, 512 is receivable in the central aperture 420, 510 and keys (not shown) are then inserted into the keyways of the central aperture 420, 510. Each tube fitted to the first die member 402, 512 includes notches, in one end, that conform to the shape and position of the keys. Thus the keys rotate the tube with as the wheel 400, 500 rotates, and both the tube and wheel 400, 500 freely rotate over the first die member 402, 512. The internal diameter of the tube must therefore not be so large that the tube can slide over the keys, but must not be so small that the tube cannot freely rotate over the first die member 402, 512. Also, with reference to Figure 2A, the distance between the wheel 268 and second die support 262 should closely match the length of the tube

206, so that the tube 206 remains in contact with the keys, but also remains longitudinally in position for accurate positioning of the perforations. That distance must be slightly larger than the length of the tube 206 – for example, by 0.1 mm longer – so that the tube 206 can still freely rotate about the first die member 230.

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Now turning to Figure 4A, the tube 422 is shown with small, closely-spaced perforations 424. A plurality of perforations 424 is punched into the tube 422 with each punching operation, and the tube 422 is then rotated by a small amount before the next plurality of perforations is formed therein. The spacing and placement  
10 accuracy of the perforations is determined, in part, by the number of teeth on wheel 400 and the accuracy with which the wheel 400 can be placed in indexing positions. Thus, the larger the diameter of wheel 400 the finer the accuracy since a small amount of tolerance between the pitch guide and wheel at a long distance, will have a lesser effect on the accuracy of positioning of the wheel than will a similar amount of  
15 tolerance at a distance closer to the axis of the wheel.

Figure 5A show a similar arrangement where tube 514 is fitted over die member 512 and perforations are formed therein with larger centre-to-centre spacing resulting from larger distances between notches 504 on the wheel 500.

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It will be noted that perforations of multiple different sizes may be simultaneously formed, provided the centre-to-centre angular spacing, or angular offset, between neighbouring perforations of each respective size is the same. Where different centre-to-centre angular spacing is required, one set of perforations is formed (e.g. the  
25 perforations 404 shown in Figure 4A), and a further set of perforations of different centre-to-centre angular spacing may then be formed (e.g. the perforations 424 shown in Figure 5A).

The product resulting from sequential formation of perforations 404, 424 is shown in  
30 Figure 6. A first set of perforations 600 is formed using the arrangement shown in Figures 4A and 4B, along with an appropriate arrangement of punches, and a second set of perforations 602 is formed using the arrangement shown in Figures 5A and 5B, along with an appropriate arrangement of punches.

35 While the wheel and punches may need to be changed where it is desired to have multiple sets of perforations with different angular spacing on a single tube, the die may remain the same. With reference to Figure 7, a die 700 is shown with apertures

702. This die can be used in the arrangement of Figures 5A and 5B, but not with the arrange of Figures 4A and 4B since the spacing between the apertures 702 will not match those between the punches, thus the punches may not be able to penetrate the tube. The die 800 shown in Figure 8, however, may be used in both the arrangement of Figures 4A and 4B, along with the arrangement shown in Figures 5A and 5B. By virtue of perforations 802, the die 800 will be able to accommodate the punches required to form perforations 424 and, similarly, by virtue of perforations 804, the die 800 will be able to accommodate the punches required to form perforations 516.

Each of the components described above may be made from any desired material. For example, most of the components of the apparatus may be formed from tool steel having a hardness of 62 to 64 HRC (Rockwell hardness). Some components that do not experience high wear, such as the indexer, may be made from tool steel with a hardness of 52 to 54 HRC.

Lastly, Figures 9 and 10 illustrate the different product (i.e. perforated tube) formed using the present invention when compared with prior art techniques. In Figure 9, a tube 900 is shown with perforations 902 formed about its peripheral wall. Notably, since the perforations 902 are formed in a flat plate that is then rolled into a tube, an unperforated space must be retained along opposite edges of the flat plate so facilitate welding along line 904. Without retaining that space, no reliable weld could be formed.

As previously discussed, it is not possible to form a single component having multiple diameters using heretofore understood methods. If a tube is swaged after perforation occurs, then the perforations would distort the shape of the tube. Thus the swaged region 906 of tube 900 is formed separately from the perforated section 908, and is welded to that section after it has been formed into a tube.

Conversely, with reference to Figure 10, a tube 1000 can be formed integrally with one or more swaged sections 1002, 1004, with perforations 1008 formed thereafter. In addition, the perforations 1008 are arranged such that any line drawn longitudinally of the tube 1000 (e.g. lines 1010 and 1012) will intersect at least one perforation 1008. In other words, there is no space for a weld, such as weld 904 of Figure 9, to be formed. Thus the present tube 1000 cannot be formed using the methods by which tube 900 is formed.

**The skilled person will thus appreciate that perforated tubes formed in accordance with present teachings are thus formed, in a broad sense, by:**

**at least partially inserting a first die member (e.g. die member 108) into a tube (e.g. tube 106);**

**5 performing a repetitive punching operation, by bringing the first die member together with a second die member (e.g. die member 110) to punch at least one perforation in the tube, and subsequently moving the first die member and second die member apart; and**

**10 rotating the tube, by a predetermined amount, between successive punching operations to punch a predetermined pattern of perforations in the tube.**

**Such a broad method may further include the step of forming a swaged region (e.g. region 1002 or 1004) in a tube (e.g. tube 1000), prior to the step of at least partially inserting a first die member into the tube.**

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## **Claims**

1. An apparatus for forming a perforated tube, comprising:  
a main support; and  
5 a die assembly mounted to the main support and comprising two opposed die members, the two opposed die members including a first die member and a second die member, the first die member having an axis and being configured to be at least partially inserted into a tube, the tube comprising a swaged section, wherein the die assembly comprises a first die support for pivotally supporting the first die member  
10 on the main support;  
wherein the apparatus is operable to perform a repetitive punching operation, by bringing the two opposed die members together, to punch at least one perforation in the tube, and subsequently moving the two die members apart, the apparatus further comprising:  
15 a rotation assembly comprising a rotation member rotationally mounted to the main support, the rotation member rotating the tube, by a predetermined amount, between successive punching operations to punch a predetermined pattern of perforations in the tube.
- 20 2. The apparatus according to Claim 1, wherein the rotation assembly is configured to rotate the tube about the axis of the first die member.
3. The apparatus according to Claim 1 or 2, wherein one of the two opposed die members comprises at least one punch, and the other of the two opposed die  
25 members comprises a corresponding aperture for each punch, each aperture being located to receive a respective punch during punching operations.
4. The apparatus according to Claim 3, wherein the first die member comprises the one or more apertures.  
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5. An apparatus according to Claim 4, wherein the first die member comprises a slug collection recess for collecting slugs punched from the tube during punching the predetermined pattern of perforations.
- 35 6. An apparatus according to Claim 5, wherein the slug collection recess comprises an elongate through-hole extending axially of the first die member.

7. An apparatus according to any preceding Claim, wherein the die assembly comprises a guide assembly for guiding movement of the two opposed die members as they are brought together.

5        8. An apparatus according to Claim 7, wherein the guide assembly comprises a stripper moveable with the second die member for contacting the tube to maintain a position of the tube as the two opposed die members are brought together.

10       9. An apparatus according to Claim 7 or 8, wherein the guide assembly comprises at least one pilot pin receivable in a corresponding pilot pin aperture as the two opposed die members are brought together.

15       10. An apparatus according to Claim 9, wherein the corresponding pilot pin aperture is located towards an end of the first die member.

15       11. An apparatus according to Claim 9, wherein the guide assembly comprises two pilot pins receivable in two corresponding pilot pin apertures, the corresponding pilot pin apertures being located toward respectively opposite ends of the first die member.

20       12. An apparatus according to Claim 1, wherein the first die member is connected to the first die support by a hinge.

25       13. An apparatus according to Claim 1 or 12, wherein the first die member is pivotally movable between a loading condition, in which a perforated tube can be removed from the first die member and the first die member can be received in a further tube, and a punching condition, in which the first die member is in a position in which the further tube is retained over the first die member.

30       14. An apparatus according to any one of Claims 1 to 13, wherein the die assembly comprises a second die support, the first die support and second die support supporting portions of the first die member at opposite ends of the further tube during punching operations.

35       15. An apparatus according to Claim 14, wherein the second die support has an upper surface configured to receive the first die member.

16. An apparatus according to Claim 14 or 15, wherein the further tube is retained, in use, between the first die support and a second die support, the first die member being in contact with the second die support when in the punching condition and being not in contact with the second die support when in the loading condition.

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17. An apparatus according to any one of Claims 14 to 16, wherein the first die support and second die support maintain the first die member in alignment with the second die member during punching operations.

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18. An apparatus according to any preceding Claim, wherein the apparatus is operable to perform a repetitive punching operation by bringing the second die member down upon the first die member, thereby capturing the tube between the two die members during each punching operation.

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19. An apparatus according to Claim 18, wherein the second die member comprises a plurality of punches each of which is configured to form a respective perforation in the tube during each punching operation.

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20. An apparatus according to any preceding Claim, wherein the rotation member comprises an indexing wheel and the rotation assembly further comprises an indexer, the indexing wheel having an index position for each punching operation to be performed on the tube and the indexer being for rotating the indexing wheel, with the tube, to successive indexing positions between respective punching operations.

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21. An apparatus according to Claim 20, wherein the rotation assembly further comprises a pitch guide movable into contact with the indexing wheel to maintain the indexing wheel in a respective indexing position during punching of holes in the tube, and movable out of contact with the indexing wheel to permit rotation of the indexing wheel to another of the indexing positions.

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22. An apparatus according to Claim 21, wherein the indexing wheel comprises a sawtooth peripheral edge and the pitch guide comprises a triangular notch, the triangular notch receiving a tooth of the sawtooth peripheral edge to maintain the indexing wheel in the respective indexing position.

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23. An apparatus according to Claim 22, wherein the indexing wheel comprises a peripheral edge having a plurality of spaced notches, and the pitch guide comprises a

rounded end, the rounded end being receivable in a respective one of the spaced notches to maintain the indexing wheel in the respective indexing position.

**24. A method for forming a perforated tube, comprising:**

5        **forming a swaged section in a tube;**  
      **at least partially inserting a first die member into the tube;**  
      **performing a repetitive punching operation, by bringing the first die member**  
**together with a second die member to punch at least one perforation in the tube, and**  
**subsequently moving the first die member and second die member apart; and**  
10       **rotating the tube, by a predetermined amount, between successive punching**  
**operations to punch a predetermined pattern of perforations in the tube, wherein the**  
**first die member and the second die member forms part of a die assembly mounted**  
**on a main support, the die assembly comprising a first die support for pivotally**  
**supporting the first die member on the main support.**

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**25. A perforated tube formed by the apparatus of any one of Claims 1 to 23, the tube comprising a plurality of perforations arranged such that any line drawn longitudinally of the tube will intersect at least one perforation.**

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**26. A perforated tube formed by using the method of Claim 24, the tube comprising a plurality of perforations arranged such that any line drawn longitudinally of the tube will intersect at least one perforation.**