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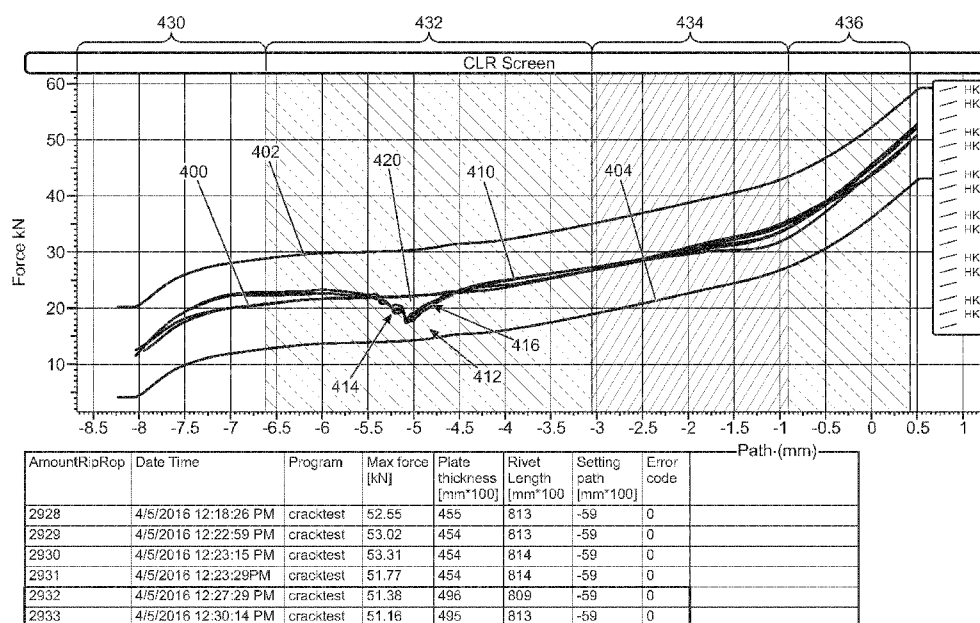
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PIERCING RIVET

Fig. 4

(57) Abstract: Embodiments of the present invention provide a method of detecting material cracking during installation of a self-piercing rivet (SPR) using an SPR gun. The method comprises: measuring reaction force and displacement at the SPR gun; comparing a resulting force against displacement curve for the installation against a reference curve for a good installation; and generating a rivet installation alert if a deviation of the force against displacement curve below the reference curve by more than a predetermined amount occurs. A controller for detecting material cracking using the method is also disclosed.



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METHOD AND CONTROLLER FOR DETECTING MATERIAL CRACKING DURING INSTALLATION OF A SELF-PIERCING RIVET

TECHNICAL FIELD

5 The present disclosure relates to a method and a controller for detecting material cracking during installation of a self-piercing rivet (SPR), and particularly, but not exclusively, to a vehicle comprising panels joined with SPRs installed according to the method.

10 BACKGROUND

Self-piercing rivets (SPRs) are used to mechanically join work pieces. The work pieces to be joined can include thin sheet, high-strength steel sheet (of different alloys), stainless steel sheet, aluminium and alloys thereof, magnesium (any of which may be galvanised, coated or uncoated), or fibre reinforced plastics (FRP). Two or
15 more work piece layers, which may be the same or different materials, can be joined with such SPR mechanical joining technology. No pre-drilling of the work pieces is required. The technology has proven beneficial in vehicle manufacture, in particular, but not exclusively, for joining body panels.

20 SPRs are installed using an SPR gun, which includes a die or punch that is used to press the rivet through the work pieces to be joined. A die plate or anvil on the back side of the joint, opposite to the punch, includes a die cavity that is sized and shaped to ensure an optimal deformation of the rivet as the punch is urged towards the anvil. The punch is typically urged towards the anvil under hydraulic, pneumatic or
25 electrical power, but manual application of force is also possible. The lower sheet layer is not penetrated in the process. Due to the deformation of the rivet and of the adjacent material of the work pieces that are being joined, an interlocking connection is created.

30 A cross-section through a typical SPR joint 10 is shown in Figure 1. An upper sheet or panel 100 and a lower sheet or panel 102 are mechanically joined together by an SPR 50. The SPR 50 in this example is a semi-tubular rivet, having a head portion 52 and a generally tubular body portion 54 depending from the head portion 52. A bottom end 56 of the body portion 54 may be profiled to have a piercing edge. During
35 installation of the SPR 50, as the punch of the SPR gun (not shown) moves down towards the anvil (not shown), the bottom end 56 of the body portion 54 of the SPR 50 pierces the upper sheet 100 and the underlying material is deformed into the die

cavity. As the punch continues towards the anvil, the body portion 54 is splayed outwardly, forming an undercut 58, which in this example is 0.61 mm on a left-hand side of the cross-section and 0.55 mm on a right-hand side, thereby positively joining the upper sheet 100 and the lower sheet 102 together. A remaining base thickness
5 60 in this example is 0.83 mm. The head portion 52, in this example, projects beyond the top surface 100a of the upper sheet 100 by a distance of 0.16 mm.

The SPR installation process may be automated, with individual SPRs being separated out from a bin and conveyed to the punch of the SPR gun through a feed
10 tube by means of compressed air. A magazine can also be used for the feeding process.

Cracking of the material in the region of an SPR joint can occur, in particular in the lower sheet 102, as shown in Figure 2. In this cross-section through a cracked joint, a
15 first crack 200 can be seen emanating from the right-hand side (as viewed) of the bottom end 56 of the SPR body portion 54. A second crack 202 can be seen emanating from the left-hand side (as viewed) of the bottom end 56 of the SPR body portion 54. The second crack 202 has gone all the way through the lower sheet 102, resulting in a separation 204 of the lower sheet 102 from the upper sheet 100,
20 propagating substantially horizontally across the bottom end 56 of the SPR at an interface between the bottom surface 100b of the upper sheet 100 and the top surface 102a of the lower sheet 102.

Such cracking might have implications if left unsealed as moisture may get into the
25 joint and galvanic corrosion may occur. However, due to the nature of mechanical joints made using the SPR installation process, inspection of such joints can be difficult and can require destructive testing, for example during vehicle teardown. Accordingly, such cracking may go undetected.

It is known to monitor installation process data such as force-path development, sheet thickness and rivet length. An error alert can be displayed if the values deviate beyond specified tolerances. For example, it is known that if the sheet thickness or rivet length are detected to be outside of tolerances, the system can be stopped before riveting starts, thereby preventing expensive rejects. By reference to Figure 3,
30 which is an illustrative example force-path development plot of a SPR gun monitoring system, actual force-path development 300 (i.e. reaction force at the punch against displacement of the punch, ergo of the rivet) for an SPR installation can be plotted
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against an expected force-path development envelope 310 for a particular set of conditions (e.g. materials and thicknesses of the sheets being joined; the type of SPR; the shape of the die plate). Upper and lower bounds 312, 314, respectively, can be set on either side of the envelope 310 and if the actual force-path development 300 deviates beyond either of those upper and lower bounds 312, 314, then an error alert can be generated, indicating a potential problem with that installation. However, even with SPR installation carried out with such monitoring, the occurrence of cracking may not be detected, for reasons explained below.

It is an object of embodiments of the invention to at least mitigate one or more of the problems of the prior art.

SUMMARY OF THE INVENTION

Aspects and embodiments of the invention provide a method and a controller for detecting material cracking during installation of a self-piercing rivet (SPR), and a vehicle comprising panels joined with SPRs, as claimed in the appended claims.

According to an aspect of the invention, there is provided a method of detecting material cracking during installation of a self-piercing rivet (SPR) using an SPR gun, comprising measuring reaction force and displacement at the SPR gun, comparing a resulting force against displacement curve for the installation against a reference curve, and generating a rivet installation alert if a drop in reaction force resulting in a deviation of the force against displacement curve below the reference curve by more than a predetermined amount occurs. Advantageously, cracking of material during installation of an SPR can be detected early during that installation using this method so that appropriate remedial action can be taken. A drop in the reaction force can be indicative of material cracking, so this characteristic is specifically monitored for in the curve.

According to an embodiment of the invention, the predetermined amount of deviation corresponds to an absolute drop in value of the reaction force. Alternatively or additionally, the predetermined amount of deviation may correspond to a relative drop in value of the reaction force. Advantageously, an amount of deviation that will trigger a material cracking alert can thus be determined on the basis of one or more of a number of different parameters, and can depend on the properties of the material or materials being joined. In some circumstances, the alert may simply be based on an absolute drop in value of the reaction force, such as a 3 kN drop being

detected. Optionally, the predetermined absolute drop is in the range of 1 to 5 kN, it may be in the range of 2 to 4 kN, or it may be about 3 kN – i.e. $3 \text{ kN} \pm 10\%$. In some circumstances, the alert may instead be based on a relative drop in value of the reaction force, such as a 5% drop from the level of the force prior to the drop occurring. Optionally, the predetermined relative drop is in the range of 1 to 10%, it may be in the range of 3 to 8%, it may be about 5% - i.e. in the range of 4.5% to 5.5%. In some circumstances it could be advantageous to take both an absolute value and a relative value into consideration for determining if an alert should be generated. The predetermined amount of deviation may be smaller than would result in the force against displacement curve crossing the lower bound. Thus, an alert can be generated even where the force against displacement curve remains within an operating envelope, and which therefore might otherwise not have indicated a potential problem with that installation.

According to an embodiment, the predetermined amount of deviation further corresponds to the displacement over which the reaction force is below the reference curve by more than a predetermined amount. Thus, both the amount of the drop in the reaction force (whether absolute or relative) and the duration (in terms of displacement, or rivet path) for which a deviation below the reference curve is detected can be taken into account for determining if an alert should be generated. The area below a force against displacement curve represents the work done by the force. Accordingly, the area of a region of deviation between the force against displacement curve for the installation and the reference curve represents the amount of work less than expected for a reference 'good' installation – i.e. an installation that meets a predetermined quality standard (which might correspond to substantially no material cracking). Thus, by taking into account the displacement as well as the drop in force, the alert can be generated on the basis of a deviation from an expected amount of work required to install an SPR.

In an embodiment, the reference curve is selected on the basis of parameters of the material or materials being joined by the SPR. Advantageously, the alert can therefore be generated on the basis of parameters specific to the particular material or combination of materials that are being joined together by the SPR in the installation.

In an embodiment, the reference curve is generated from data measured during a previous installation of an SPR in material or materials having substantially the same

parameters as those of the current installation and which previous installation has proven to meet a predetermined quality threshold (i.e. proven to be good). Advantageously, where a prior installation has been proven to be good, the force and displacement measurements data from the prior installation can be used, so there
5 may be no need to resort to simulation.

In another embodiment, the reference curve is generated via a simulation. Advantageously, this means that a theoretical, computer-modelled curve can be used as the reference curve in addition to, or as an alternative to, using a reference curve
10 from a previous installation. In this way, if an SPR joint is desired, using potentially different materials and/or of different thicknesses compared to what has previously been used, and where little or no empirical data is available, the riveted joint can be verified using a simulation generated curve and compared with the force and displacement measurements taken during the riveting process. Once the SPR is
15 installed in this new combination of materials and/or different thicknesses, it is then tested to assure the quality of the joint, checking that the finished installation is in fact good, or if it resulted in material cracking. In this way, each joint can be verified during the riveting process even if empirical data is limited.

20 In an embodiment, the predetermined amount of deviation is determined on the basis of parameters of the material or materials being joined by the SPR. Accordingly, the generation of the alert can be made on the basis of the material parameters for the particular installation rather than, say, generic predetermined values.

25 In an embodiment, the predetermined amount of deviation occurs within a characteristic 'flat' region of the reference curve. Advantageously, only that region of the curve needs to be analysed or deviations from other portions of the curve can be ignored because it is during the characteristic flat region, which corresponds to the SPR being urged through the materials being joined, and during which part of the
30 installation cracking is most likely to manifest.

In an embodiment, the deviation below the reference curve is temporary, and the force against displacement curve re-joins into approximate alignment with the reference curve. The deviation below the reference curve may not be permanent and
35 may instead be a temporary dip below the reference curve. Such a characteristic dip of the measured force against displacement curve below the reference curve is indicative of material cracking, provided the dip is of sufficient size. By approximate

alignment, is meant that the force against displacement curve is within a certain range of the reference curve, the certain range being less than the predetermined amount.

5 In an embodiment, the method comprises setting a lower tolerance band for the reference curve, wherein the predetermined amount of deviation corresponds to a predefined proportion of the tolerance band. The predefined proportion may, by way of example, be 50%. Accordingly, a relatively wide operating envelope defined by the lower tolerance band (typically in conjunction with an upper tolerance band also) can
10 in effect be split into sub-bands and deviations of the force curve that remain within the sub-band closest to the reference curve do not trigger an alert, so allowing for a certain amount of 'wobble' in the alignment of the force-displacement curve compared to the reference curve. A larger drop of the force-displacement curve could take it below the lower bound and trigger a first type of error alert which could be
15 indicative of a misalignment of the SPR in the die, or some other set-up error. Any drop in the force-displacement curve falling between the permitted wobble and the lower bound (i.e. which takes the curve within the next sub-band) may thus trigger a second type of error alert, indicative of potential material cracking.

20 In an embodiment, the material or materials being joined by the SPR comprises one or more metallic components. In certain embodiments, the metallic components are aluminium or alloys thereof. Optionally, the components comprise panels. Optionally, the components may be pre-strained. In embodiments, the amount of pre-strain may be approximately 15%.

25 According to an aspect of the invention, the method further comprises creating a unique identifier for the installation and storing a log of data for the installation together with the unique identifier. The data may include one or more of: the measured reaction force, the measured displacement, the reference curve, and
30 whether an alert has been generated for the installation. Advantageously, a log of installations can be made for later reference. In particular, the log can include details of every installation which resulted in an alert being generated, and can include the data specific to those 'failed' installations so that it can be referenced subsequently in order to determine what action to take.

35 According to another aspect of the invention, there is provided computer software which, when executed by a computer, is arranged to perform a method according to

an aspect of the invention. Optionally, the computer software is stored on a computer-readable medium. The software may be tangibly, non-transiently stored on the computer readable medium.

- 5 According to another aspect of the invention, there is provided a controller for detecting material cracking.

In an embodiment, there is provided an input for receiving data indicative of a force and displacement of a self-piercing rivet (SPR) during installation of the SPR.

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In an embodiment, there is provided comparator means for comparing a resulting force against displacement curve for the installation against a reference force against displacement curve.

- 15 In an embodiment, there is provided alert generation means for generating a rivet installation alert if a drop in reaction force resulting in a deviation of the force against displacement curve below the reference curve by more than a predetermined amount occurs.

- 20 In an embodiment, the controller further comprises storage means for storing a log of data for the installation together with a unique identifier for the installation. The data may include one or more of: the measured reaction force, the measured displacement, the reference curve, and whether an alert has been generated for the installation.

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According to an aspect of the invention, there is provided an assembly comprising components joined with SPRs installed according to the method of an aspect of the invention. The assembly may be a vehicle and the components may comprise panels.

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According to an aspect of the invention, there is provided a method of detecting material cracking during installation of a self-piercing rivet (SPR) using an SPR gun is disclosed. The method comprises measuring reaction force at the SPR gun, detecting if a drop in reaction force greater than a predetermined value occurs, and
35 generating a rivet installation alert in response to the detected drop in reaction force.

According to an aspect of the invention, there is provided a controller for detecting material cracking during installation of a self-piercing rivet (SPR) is also disclosed. The controller comprises an input for receiving data indicative of a force and displacement of a self-piercing rivet (SPR) during installation of the SPR, and alarm generation means for generating an alarm if a drop in reaction force greater than a predetermined value is detected.

According to an aspect of the invention, there is provided an apparatus for detecting material cracking during installation of a self-piercing rivet (SPR) is also disclosed. The apparatus comprises an SPR gun, force detecting means for detecting a reaction force at the SPR gun, and alarm generation means for generating an alarm if a drop in reaction force greater than a predetermined value is detected.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the invention will now be described by way of example only, with reference to the accompanying figures, in which:

Figure 1 shows a self-piercing rivet joining two sheets of material in a good installation;

Figure 2 shows a self-piercing rivet joining two sheets of material in an installation in which material cracking has occurred;

Figure 3 shows a known force against displacement plot, plotting force of installation of a rivet against its path of insertion;

Figure 4 shows a force against displacement plot, showing curves for good installations and for installations where cracking has occurred;

5 Figure 5 shows a method according to an embodiment of the invention; and

Figure 6 shows a vehicle comprising a system according to an embodiment of the invention.

10 DETAILED DESCRIPTION

It has been determined by the inventors that material cracking at joints formed by SPR installation can be detected by observing that a temporary drop in the reaction force at the SPR gun occurs when a crack initiates.

15 Figure 4 shows a force against displacement (or path) plot, showing two curves 400 for 'good' installations (i.e. installations which have passed a quality control; where no, or substantially no material cracking has occurred) and four curves 410 for installations where cracking has occurred. Either of the curves 400 (or an average of the two) may be taken as a reference curve for a 'good' installation. The plot also
20 includes upper and lower bounds 402, 404 respectively, corresponding to the upper and lower bounds 312, 314 of the prior art and as shown on Figure 3. These upper and lower bounds 402, 404 may, by way of example, be set to define a tolerance band of ± 8 kN either side of the reference curve 400.

25 The reference curve 400 for a good installation can be derived experimentally or empirically from previous installations for a particular set of conditions corresponding to the current SPR installation. For example, the force against displacement data from a previous installation of the same (or sufficiently similar) type of SPR in the same (or sufficiently similar) type of work pieces and which installation has proven to
30 have been a good one (i.e. no cracking occurred) can be taken as an exemplary reference curve. An average of multiple such previous installations may be used instead. Alternatively, a reference curve 400 can be derived from one or more simulations – such as a computer-implemented simulation run with parameters corresponding to the current SPR installation.

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The curves 410 where cracking has occurred all exhibit a characteristic temporary dip 412 of the curve 410 below the reference curve 400. The dip 412 comprises a

downward sloping portion 414 in which the force required for inserting the SPR is dropping, followed by an upward sloping portion 416 in which the force required for inserting the SPR increases relatively rapidly, such that the curve 410 re-joins into approximate alignment with the reference curve 400.

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By monitoring for the occurrence of such a drop in reaction force resulting in a deviation of the force against displacement curve 410 below the reference curve, the occurrence of material cracking at the joint can be detected. A rivet installation alert can be generated and appropriate action can be taken in response. The alert may be triggered if a drop of the reaction force of more than a predetermined amount is detected. That predetermined amount may be an absolute value, such as a drop of 3 kN (as measured from the highest measured force during the installation up to that point), or may be a relative drop in the value of the reaction force, such as a drop of 5% (also as measured from the highest measured force during the installation up to that point). The alert may be based on a combination of absolute and relative values. The predetermined amount is selected so as to distinguish over slight deviations from the reference curve 400 that might occur due, for example, to minor irregularities in the materials of the materials being joined, or in the SPR itself.

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In certain scenarios, any drop in the measured reaction force may be indicative of crack initiation and an alert may be generated as a result of that drop being detected. To avoid false positives, however, it can be advantageous to ensure that the drop in expected reaction force occurs for a sufficient duration – i.e. across a sufficient displacement. Thus, the alert may in some embodiments only be generated also taking into account the displacement over which the reaction force is below the reference curve (by more than a predetermined amount).

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A region 420 is defined between the reference curve 400 and the dip 412 of the curve 410. The area of this region 420 corresponds to the amount of energy less than expected to be required to urge the SPR through the work pieces into which it is being installed by the distance of the displacement (from the start of the dip 412, where the curve starts the downward slope 414 and deviates below the reference curve, to the end of the dip, where the curve 410 re-joins into approximate alignment with the reference curve 400, at the end of the upward slope 416). The alert may in some embodiments be generated on the basis of the detection of a less than expected amount of energy used to insert the SPR a given distance into the joint. The alert may therefore be based on the size of the area 420.

The predetermined amount of deviation and/or the displacement across which that deviation is to have occurred and/or the size of the area 420 that will trigger an alert may be determined on the basis of parameters of the work pieces being joined: their material or materials; their thicknesses; the amount to which they have been pre-strained; the type of SPR; the shape of the die plate the specific joint configuration, etc.

The curve 410 is considered to be in approximate alignment with the reference curve 400 when it is within a certain specified range of the reference curve 400. In the example shown in Figure 4, which refers to a particular material stack made of two layers of aluminium alloy AC600T4, the curve 410 comes into approximate alignment with the reference curve 400 after the upward sloping portion 414 to within about ± 1 kN. As discussed above, a drop below the reference curve 400 by more than a predetermined amount (which will depend on the materials being joined) is indicative of material cracking, and the certain range can be specified to be a value less than that of the predetermined amount.

Accordingly, for joints formed between two sheets of aluminium material or alloys thereof, such as 6000 series aluminium, the predetermined amount to define a material cracking event may be set at 3 kN, whereas the certain range to define approximate alignment may be set at ± 1 kN.

However, the level of alignment is application oriented and may depend on the rivet/die combination, mechanical properties and thickness of the substrate materials. The range could be higher than 1 kN for other cases. For example, for cast materials, which would typically be more brittle than aluminium or its alloys, the fracture mechanism is different and accordingly the predetermined amount to define a material cracking event may be greater, perhaps set at 5 kN, and as such a wider tolerance for determining alignment with the reference curve can be permitted, so the certain range to define approximate alignment may be set at ± 3 kN in this scenario.

In certain embodiments, the predetermined amount may be set by reference to the tolerance bands defining the upper and lower bounds 402, 404. More particularly, the predetermined amount may be set as a proportion of the tolerance band between the reference curve 400 and the lower bound 404 – i.e. an alert would be triggered if the curve 410 were to deviate below the reference curve 400 by more than 50% of

the tolerance band. By way of example, if the lower bound 404 were to be set at -6 kN from the reference curve, then the predetermined amount could be set at 50% of that: -3 kN, whereas if the lower bound 404 were to be set wider, at say -8 kN, then the predetermined amount (if still defined as 50% of the tolerance band) would be -4 kN. Thus, where wider tolerance bands have been set, which may be useful for materials having more variation in properties, the predetermined amount by which the curve 410 must deviate below the reference curve 400 before an alert is triggered is correspondingly greater. This can be useful to avoid false positive alerts; the alignment between the curve 410 and the reference curve 400 can in effect be more approximate where a wider tolerance band is set.

The curves 400, 410 have characteristic profiles corresponding to different stages of the SPR installation. In a first region 430, the force increases relatively rapidly with respect to the displacement (the path of insertion). This corresponds to an indentation stage, where the bottom end 56 of the SPR 50 is initially biting into (i.e. piercing) the top surface 100a of the upper sheet 100, requiring increasing amounts of force for the bottom end 56 of the SPR 50 to be fully inserted into the upper sheet 100. Next, in a second region 432, the force of insertion is relatively constant (for a good installation) as the SPR 50 is urged to continue to pierce and pass through the upper sheet 100 and to begin to flare the bottom end 56 of the SPR (i.e. deform to splay outwardly) into the lower sheet 102, beginning to form the lower sheet into a characteristic anvil profile. Thus, the curve 400 is quite flat over the second region 432, although, as in the example illustrated in Figure 4, there may be an overall upward trend of the curve – especially towards the latter half of the ‘flat’ region 432. In the next region, third region 434, the force required to urge the SPR further into the layers of material increases steadily as the SPR is urged to flare into the lower sheet 102. In a final, fourth, region 436, the force required for a given displacement increases relatively rapidly once again as the lower sheet 102 is urged fully into the die cavity.

It will be seen that the characteristic dip 412 in the curve 410 corresponding to the occurrence of cracking is within the flat second region 432. Thus, analysis of the curve may be constrained to just the second region 432, thereby saving on resources. However, it will be understood that material cracking may occur at any point, so analysis of the whole curve 410 may be undertaken for greater confidence in catching all occurrences of material cracking.

If a rivet installation alert is generated, then appropriate remedial action can be taken. Examples of such remedial action include: stopping the particular installation; altering the way in which the rest of the particular installation or series of installations is done; flagging the particular installation as 'no go, for future remedial action; installing
5 additional SPRs in proximity to the particular installation; and carrying out other corrective work to repair the cracked material, such as a sealing operation.

To assist in carrying out such remedial actions, particularly when a particular installation is one of a series of installations (e.g. corresponding to the number of
10 rivets needed for joining vehicle panels together) each installation may be accorded a unique identifier for later reference. A log of data for the particular installation, such as one or more of the force against displacement plot 410 for that installation, the corresponding reference curve 400, the type of SPR and the parameters of the work pieces being joined, as well as whether or not an alert has been generated, may be
15 recorded against that unique identifier, for example in a database. Thus, each 'no go' installation can be easily identified and an appropriate remedial action can be chosen.

The log of data may be used to create a lookup table to be used for installations, including those undertaken by simulation. This may aid to reduce the amount of time
20 required for physical set up of SPR tooling for those installations. The lookup table may be created and/or modified by reference to one or more simulations predictive of future installations.

25 Figure 5 illustrates a method 500 according to an embodiment of the invention. The method 500 is a method of detecting material cracking during installation of a self-piercing rivet (SPR) using an SPR gun.

In step 502 both a reaction force and a displacement are measured at the SPR gun,
30 as described above.

In step 504, a resulting force against displacement curve for the installation is compared against a reference curve, as described above.

35 In step 506, if a deviation of the force against displacement curve below the reference curve by more than a predetermined amount occurs, then a rivet installation alert is generated, also as described above.

Figure 6 illustrates a vehicle 600 according to an embodiment of the invention. The vehicle comprises panels joined with SPRs installed according to a method such as described above in relation to the preceding figures.

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A controller (not shown) for detecting material cracking is also disclosed. The controller comprises an input for receiving data indicative of a force and displacement of a self-piercing rivet (SPR) during installation of the SPR. The controller further comprises comparator means for comparing a resulting force against displacement

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curve for the installation against a reference force against displacement curve. The controller also comprises alert generation means for generating a rivet installation alert if a drop in reaction force resulting in a deviation of the force against displacement curve below the reference curve by more than a predetermined amount

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occurs. The alert generation means may, for example, comprise a display or a loudspeaker or other means for generating an alert signal to an assembly operator. The controller may further comprise storage means for storing a log of data for the installation together with a unique identifier for the installation. The data may include

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one or more of: the measured reaction force, the measured displacement, the reference curve, and whether an alert has been generated for the installation. The storage means may comprise computer memory. The controller may comprise part of an apparatus that comprises an SPR gun. The apparatus also comprises force measuring means for measuring a reaction force at the SPR gun. The apparatus also comprises displacement measuring means for measuring a displacement at the SPR gun during the installation. The force measuring means and/or the displacement measuring means may be integral with the SPR gun, in particular, but not exclusively, integral with a punch of the SPR gun.

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The comparator means may be comprised in a computer processor. It will be appreciated that embodiments of the present invention can be realised in the form of hardware, software or a combination of hardware and software. Any such software may be stored in the form of volatile or non-volatile storage such as, for example, a storage device like a ROM, whether erasable or rewritable or not, or in the form of memory such as, for example, RAM, memory chips, device or integrated circuits or on an optically or magnetically readable medium such as, for example, a

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CD, DVD, magnetic disk or magnetic tape. It will be appreciated that the storage devices and storage media are embodiments of machine-readable storage that are suitable for storing a program or programs that, when executed, implement embodiments of the present invention. Accordingly, embodiments provide a program comprising code for implementing a system or method as claimed in any preceding claim and a machine readable storage storing such a program. Still further, embodiments of the present invention may be conveyed electronically via any medium such as a communication signal carried over a wired or wireless connection and embodiments suitably encompass the same.

All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

Each feature disclosed in this specification (including any accompanying claims, abstract and drawings), may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

The invention is not restricted to the details of any foregoing embodiments. The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed. The claims should not be construed to cover merely the foregoing embodiments, but also any embodiments which fall within the scope of the claims.

CLAIMS

1. A method of detecting material cracking during installation of a self-piercing rivet (SPR) using an SPR gun, comprising:
 - 5 measuring reaction force and displacement at the SPR gun;
comparing a resulting force against displacement curve for the installation against a reference curve; and
generating a rivet installation alert in dependence on a drop in the reaction force resulting in a deviation of the force against displacement curve below the
10 reference curve by more than a predetermined amount.
2. The method of claim 1, wherein the predetermined amount of deviation corresponds to an absolute drop in value of the reaction force.
- 15 3. The method of claim 1, wherein the predetermined amount of deviation corresponds to a relative drop in value of the reaction force.
4. The method of claim 2 or claim 3, wherein the predetermined amount of deviation further corresponds to the displacement over which the reaction force is
20 below the reference curve by more than a predetermined amount.
5. The method of any preceding claim, wherein the reference curve is selected on the basis of parameters of the material or materials being joined by the SPR.
- 25 6. The method of claim 5, wherein the reference curve is generated via a simulation.
7. The method of claim 5, wherein the reference curve is generated from data measured during a previous installation of an SPR in material or materials having
30 substantially the same parameters as those of the current installation and which previous installation has proven to meet a predetermined quality standard.
8. The method of any preceding claim, wherein the predetermined amount of deviation is determined on the basis of parameters of the material or materials being
35 joined by the SPR.

9. The method of any preceding claim, wherein the predetermined amount of deviation occurs within a characteristic flat region of the reference curve.

5 10. The method of any preceding claim, wherein the deviation below the reference curve is temporary, and the force against displacement curve re-joins into approximate alignment with the reference curve.

10 11. The method of any preceding claim, comprising setting a lower tolerance band for the reference curve, wherein the predetermined amount of deviation corresponds to a predefined proportion of the tolerance band.

12. The method of any preceding claim, wherein the material or materials being joined by the SPR comprises one or more metallic components.

15 13. The method of claim 12, wherein the metallic components are aluminium or alloys thereof.

20 14. The method of claim 12 or claim 13, wherein the components comprise panels.

15. The method of any of claims 12 to 14, wherein the components are pre-strained.

25 16. The method of any preceding claim, comprising:
creating a unique identifier for the installation; and
storing a log of data for the installation together with the unique identifier, wherein the data includes one or more of: the measured reaction force, the measured displacement, the reference curve, and whether an alert has been generated for the installation.

30 17. Computer software which, when executed by a computer, is arranged to perform a method according to any of claims 1 to 16; optionally the computer software is stored on a computer-readable medium.

35 18. A controller for detecting material cracking comprising:
an input for receiving data indicative of a force and displacement of a self-piercing rivet (SPR) during installation of the SPR;

comparator means for comparing a resulting force against displacement curve for the installation against a reference force against displacement curve; and

5 alert generation means for generating a rivet installation alert if a drop in reaction force resulting in a deviation of the force against displacement curve below the reference curve by more than a predetermined amount occurs.

19. The controller of claim 18, comprising storage means for storing a log of data for the installation together with a unique identifier for the installation, wherein the data includes one or more of: the measured reaction force, the measured
10 displacement, the reference curve, and whether an alert has been generated for the installation.

20. An assembly comprising components joined with SPRs installed according to the method of any of claims 1 to 16.

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21. The assembly of claim 20, wherein the assembly is a vehicle and the components are panels.

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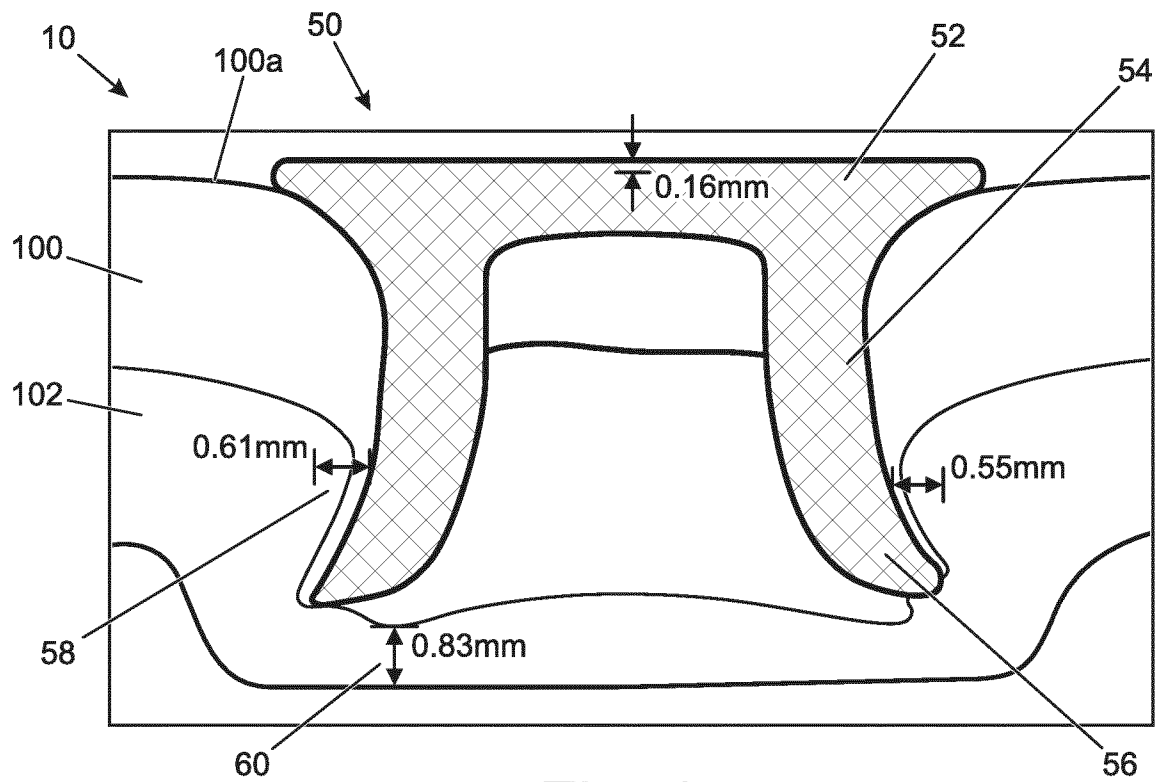


Fig. 1

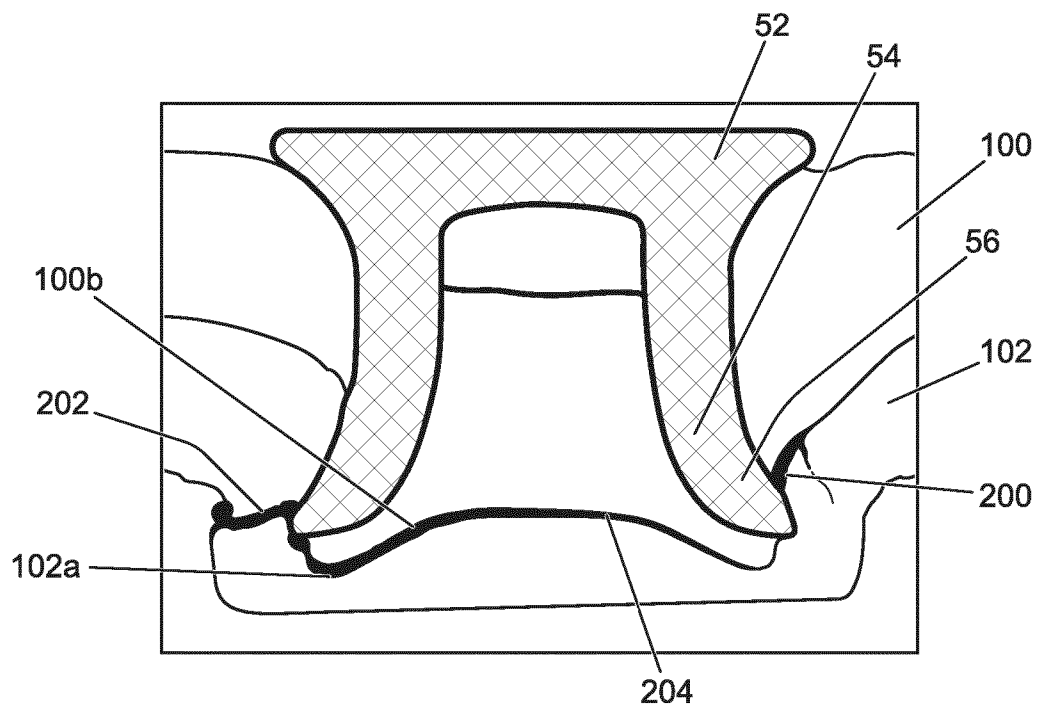


Fig. 2

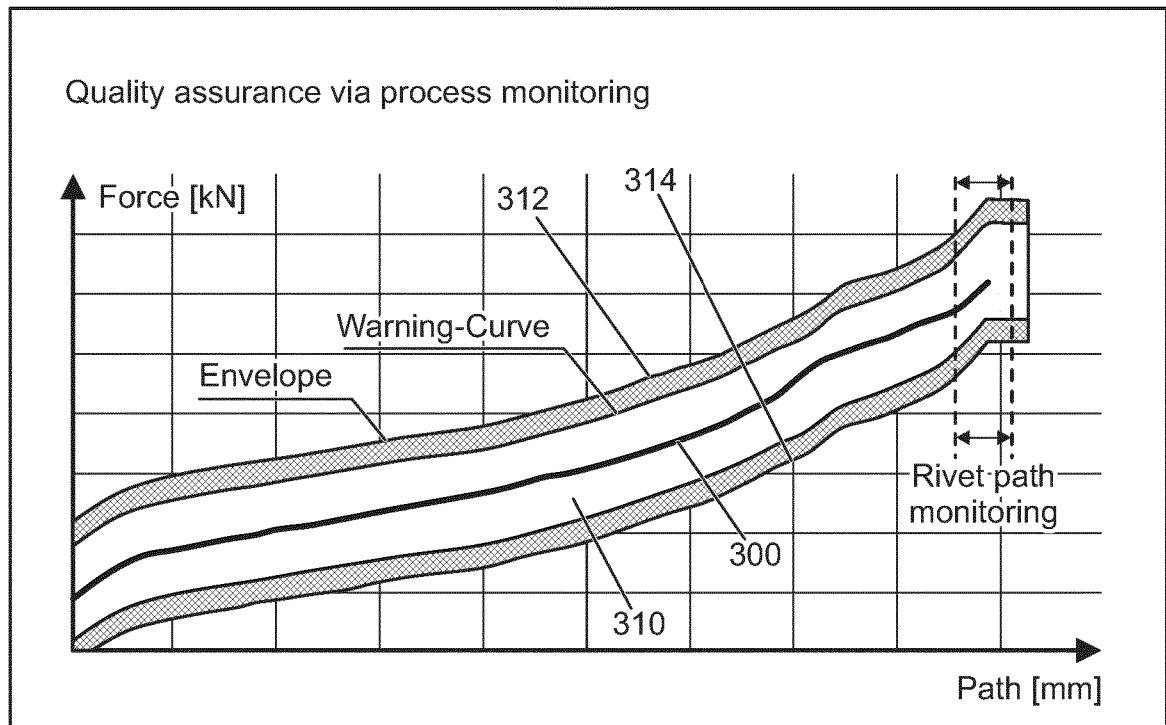
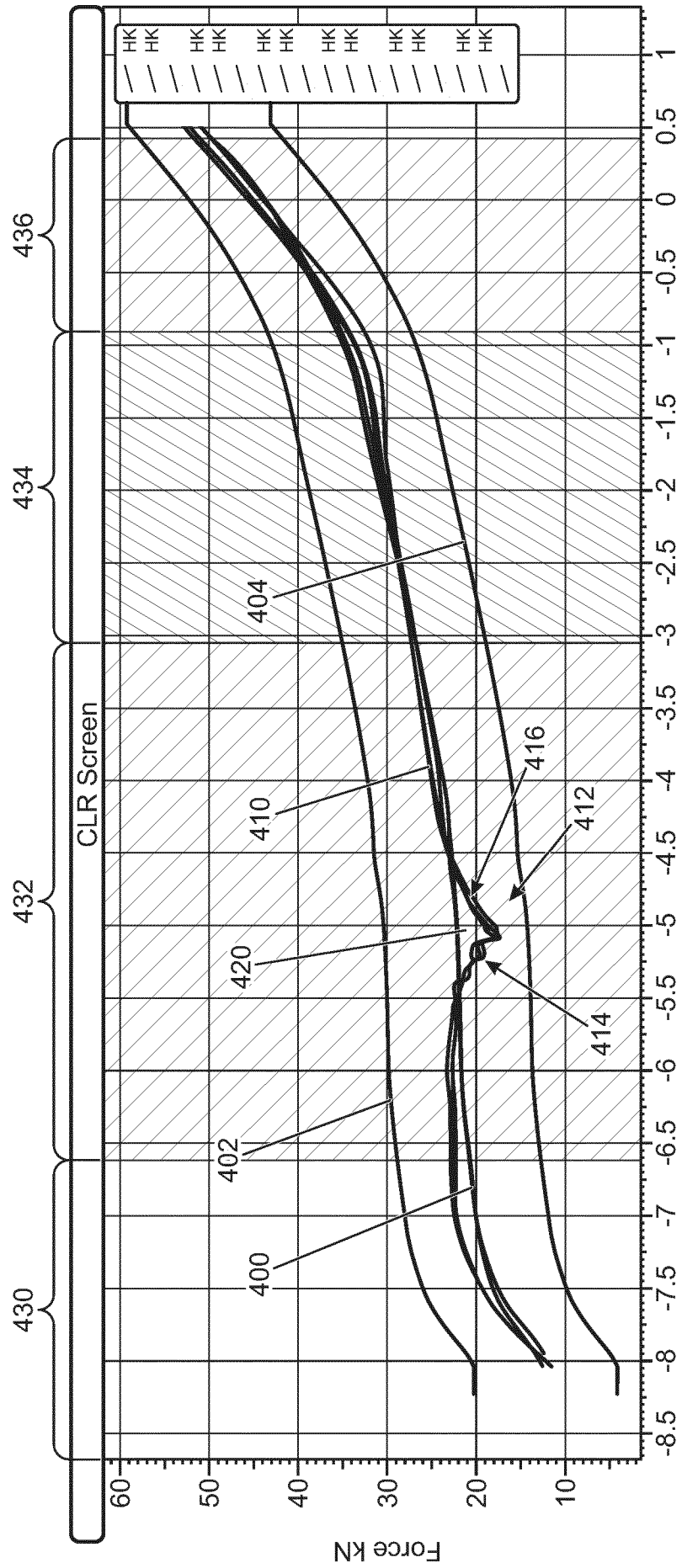


Fig. 3 (Prior Art)



AmountRipRop	Date Time	Program	Max force [kN]	Plate thickness [mm*100]	Rivet Length [mm*100]	Setting path [mm*100]	Error code
2928	4/5/2016 12:18:26 PM	cracktest	52.55	455	813	-59	0
2929	4/5/2016 12:22:59 PM	cracktest	53.02	454	813	-59	0
2930	4/5/2016 12:23:15 PM	cracktest	53.31	454	814	-59	0
2931	4/5/2016 12:23:29PM	cracktest	51.77	454	814	-59	0
2932	4/5/2016 12:27:29 PM	cracktest	51.38	496	809	-59	0
2933	4/5/2016 12:30:14 PM	cracktest	51.16	495	813	-59	0

Fig. 4

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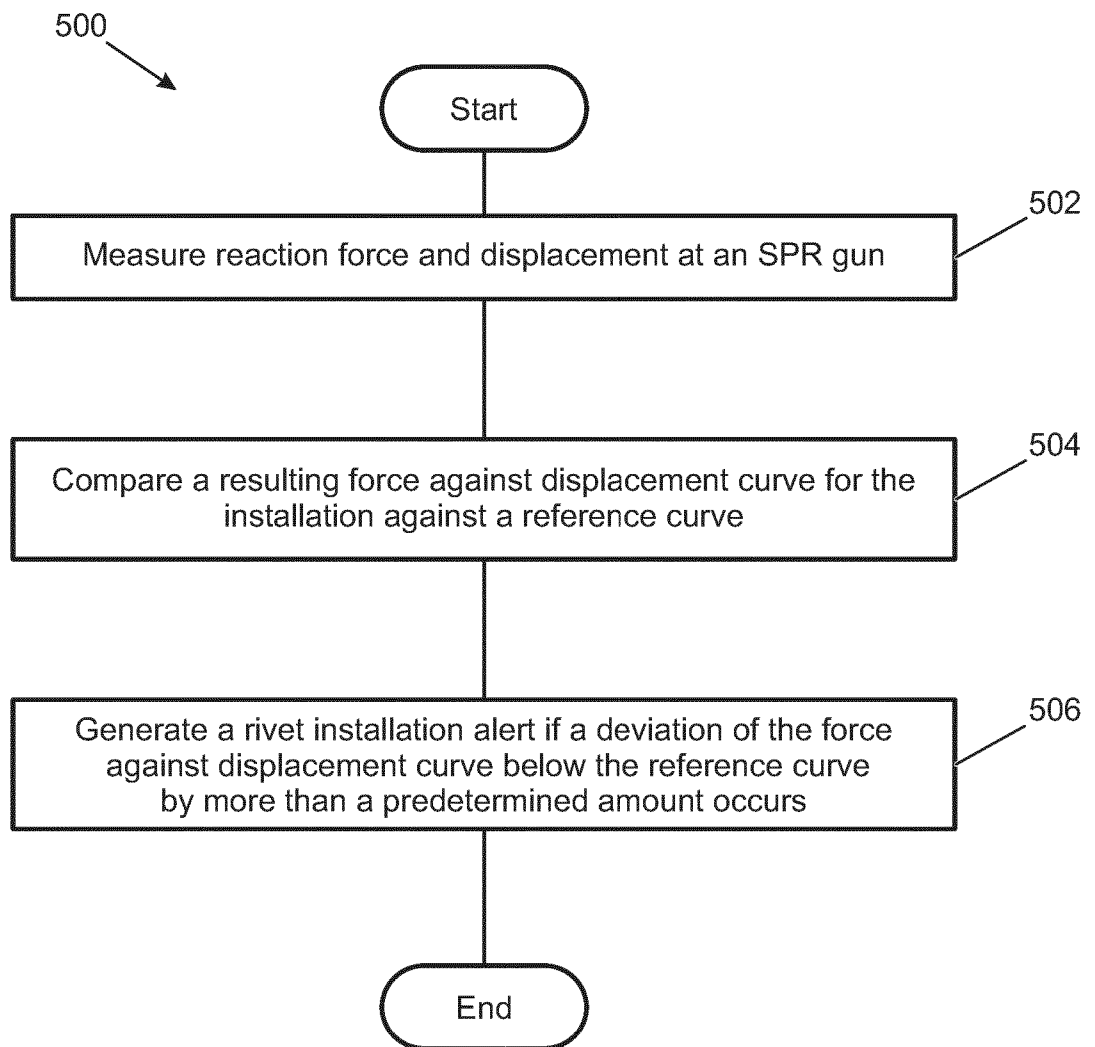


Fig. 5

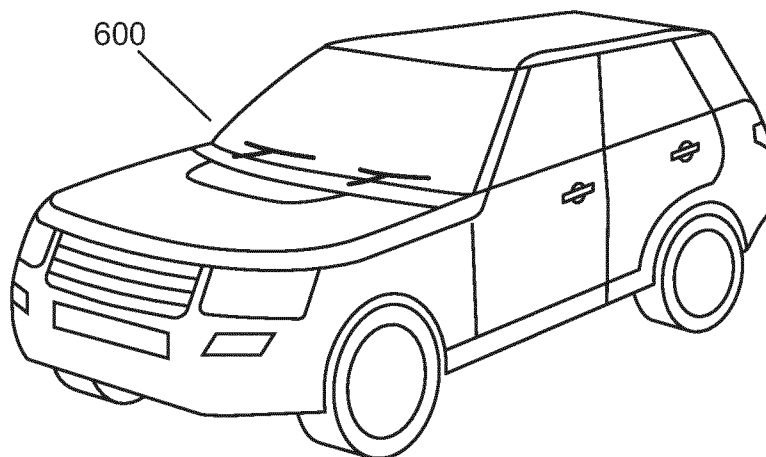


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2017/074196

A. CLASSIFICATION OF SUBJECT MATTER

INV. B21J15/02 B21J15/28
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B21J B29C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 750 869 A1 (NEWFREY LLC [US]) 14 February 2007 (2007-02-14) paragraphs [0008], [0064], [0077], [0078], [0079], [0080], [0085] - [0087]; figures -----	1-5, 7-12, 14-21
X	WO 2005/097375 A1 (NEWFREY LLC [US]; CHITTY EYMARD J [US]; TAYLOR BRIAN M [US]; THOMAS PE) 20 October 2005 (2005-10-20) paragraphs [0046], [0051], [0052], [0054], [0089], [0090], [0094]; figures -----	1-5, 7-12, 14-20
X	KR 2016 0011060 A (SUNG WOO HITECH CO LTD [KR]) 29 January 2016 (2016-01-29) paragraphs [0002], [0003], [0011], [0034] - [0039]; figures -----	1-21



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

19 December 2017

Date of mailing of the international search report

04/01/2018

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Authorized officer

Charvet, Pierre

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2017/074196

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