United States Patent [19]

Falcioni

[11] **3,874,070**

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[54] **HIGH FATIGUE SQUEEZE RIVETING PROCESS AND APPARATUS THEREFOR**

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[52] **U.S. Cl.** **29/526**, 29/243.53, 29/505, 29/509

[51] **Int. Cl.** **B23p 19/00**

[58] **Field of Search** 29/505, 509, 522, 525, 29/526, 243.53, 243.54, 432, 432.1, 432.2; 227/7, 56, 61, 62; 72/391, 386, 396, 460, 465

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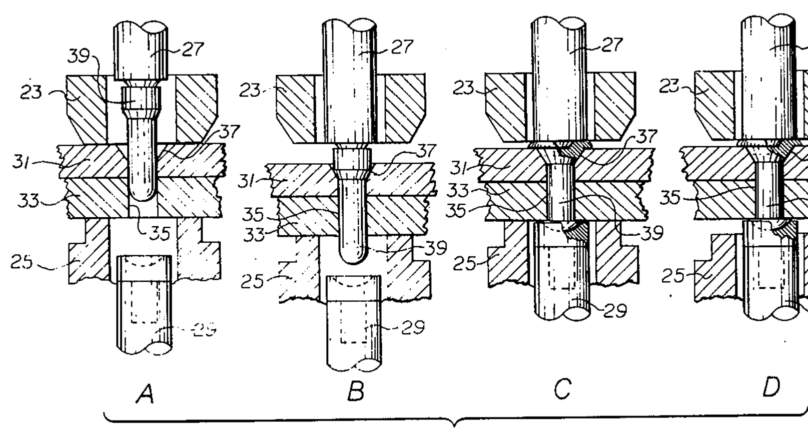
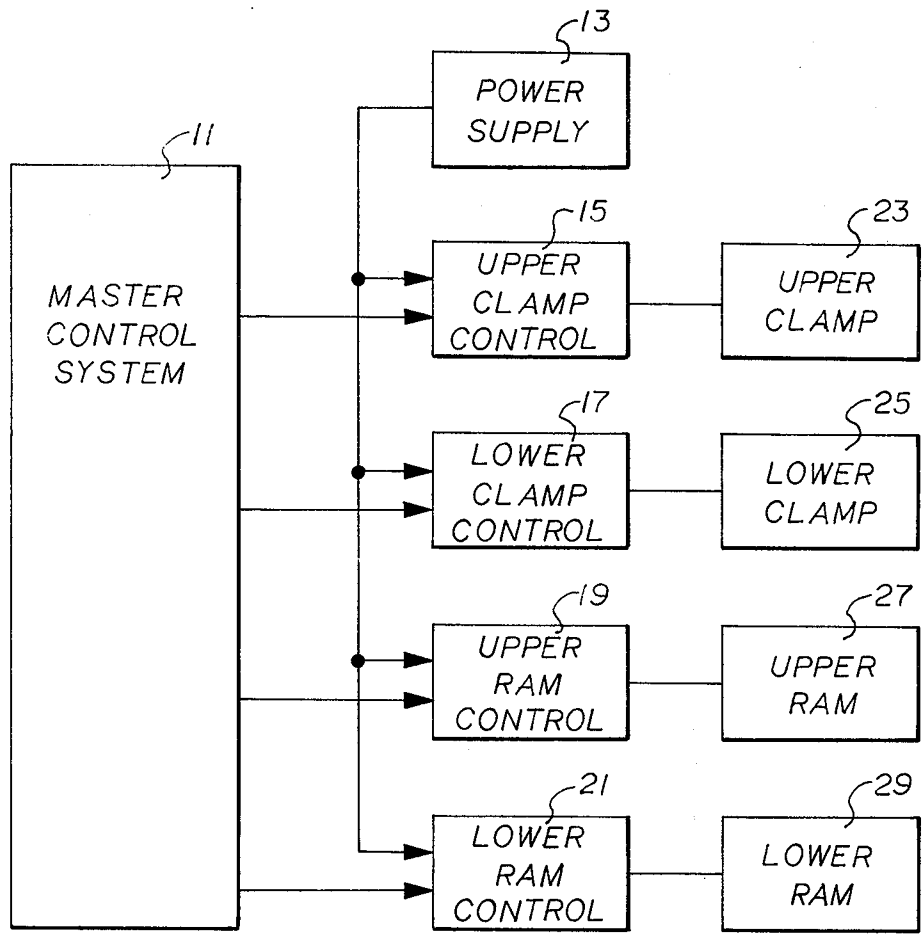
[57] **ABSTRACT**

A high fatigue squeeze riveting process and an apparatus for carrying out the process is disclosed. A pair of panels, or other items to be riveted together, are clamped by upper and lower clamps and a countersunk hole is drilled through the items. Thereafter, a shouldered rivet comprising a stud of two different diameters joined by a conical frustrum shoulder, is inserted into the hole. After insertion, upper and lower rams approach the rivet along vertical axially aligned paths. As the upper ram moves downward it presses the rivet into the hole until the shoulder thereof mates with the countersink region of the hole. As force is applied to the upper ram, the force on the upper clamp is transferred through the base of the rivet to the face of the countersink, and the work panels are gently pushed away from the surface of the upper clamp. Following release of the upper clamp, the upper ram stops moving and the lower ram impinges on the lower end of the rivet and applies a squeeze force thereto. As the force applied to the lower ram increases, the force applied to the lower clamp decreases until, just prior to upset, the lower clamp is released thereby subjecting the rivet to equal top and bottom forces.

18 Claims, 4 Drawing Figures

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POWER SUPPLY
11
MASTER CONTROL SYSTEM
15
UPPER CLAMP CONTROL
23
UPPER CLAMP
17
LOWER CLAMP CONTROL
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LOWER CLAMP
19
UPPER RAM CONTROL
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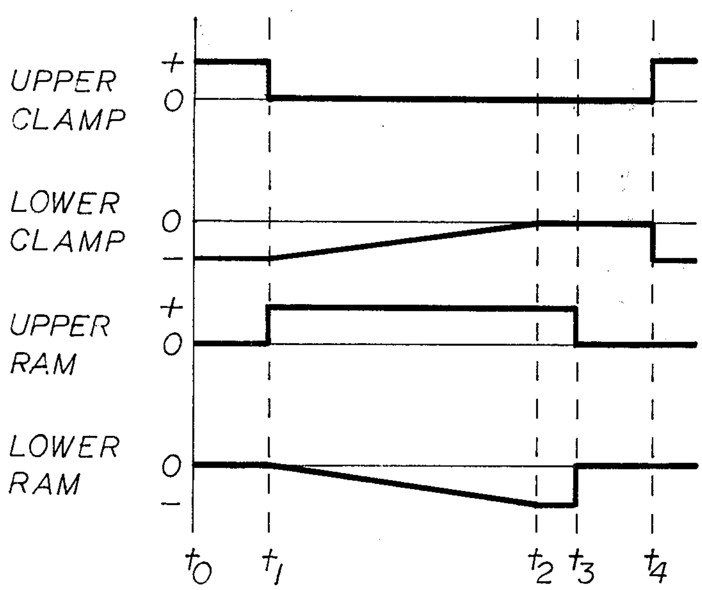
UPPER RAM
21
LOWER RAM CONTROL
29
LOWER RAM

Fig. 1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+
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t0 t1 t2 t3 t4

Fig. 2

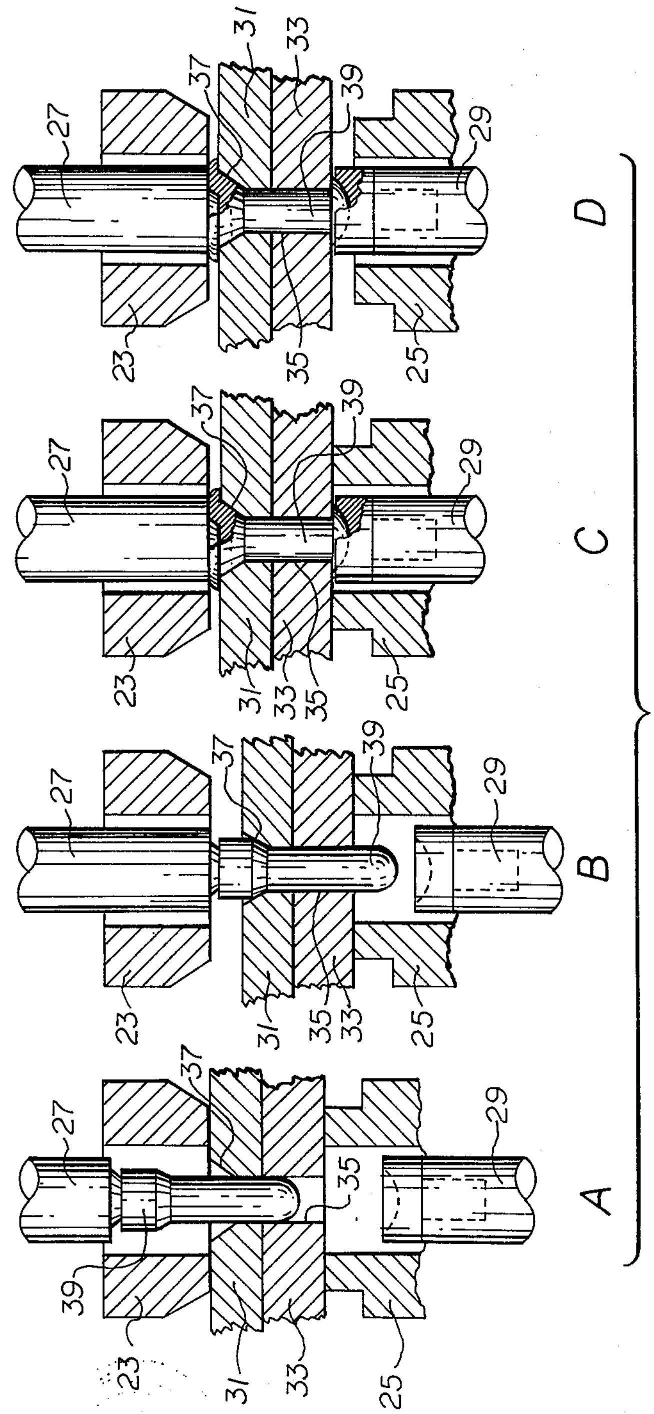

Fig. 3

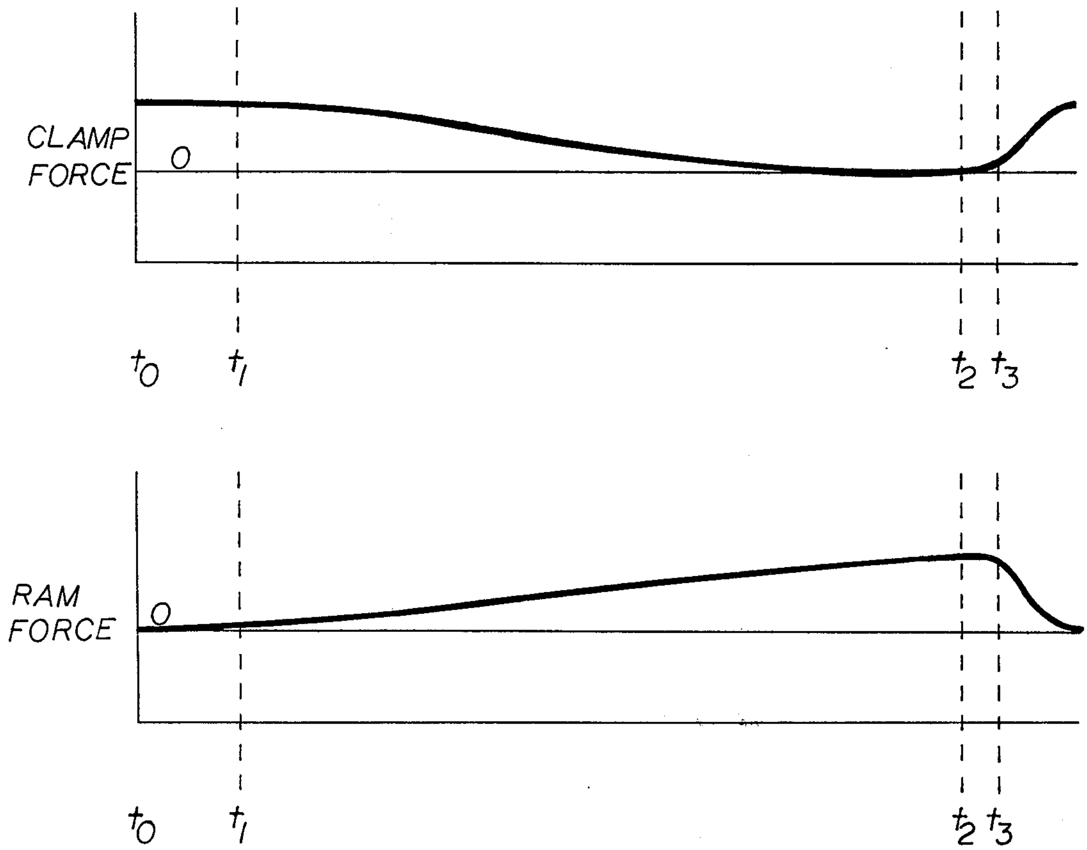

Fig. 4

HIGH FATIGUE SQUEEZE RIVETING PROCESS AND APPARATUS THEREFOR

BACKGROUND OF THE INVENTION

This invention relates to riveting processes and apparatus and more particularly to riveting processes and apparatus wherein a rivet stud is squeezed between a pair of rams.

A wide variety of squeeze type riveting processes and apparatus for carrying out the processes have been proposed and are in use. These processes and apparatus vary between those which are relatively uncomplicated to those which are relatively complicated. While some of the prior processes and apparatus have proven to be satisfactory, others have not proven to be as satisfactory or, if satisfactory, have been more expensive than desirable.

One industry wherein prior art riveting processes and apparatus have not been as satisfactory as desirable is the airframe industry. As will be understood by those skilled in the art and others, modern airframes are formed of a skeleton of structural members covered by panels formed of titanium or the like. The panels are riveted together to form an entire surface covering for a region such as a wing, for example. One commonly used prior art process for riveting the panels together (or to the structural members) is conventionally referred to as the squeeze-vibrate process. While this process has proven to be somewhat satisfactory, it is not as satisfactory as desirable. For example, the squeeze-vibrate process is noisy and, thus, contributes to noise pollution in the factories utilizing this process. Moreover, because vibration is involved, the life of the machines carrying out this process is less than it would be if vibration were eliminated. Moreover, and more importantly, the fatigue life of the thusly formed rivet joints is less than desirable. As it will be appreciated by those skilled in the airframe industry, the fatigue life of rivet joints becomes of increasing importance when high gross load aircraft are being constructed.

while the fatigue life of rivet joints formed by the squeeze-vibrate process have been improved, the improvements have been at the cost of building expensive new machinery or at the cost of extensively modifying existing machinery. Thus, the squeeze-vibrate process and the apparatus for carrying out this process have certain disadvantages.

Another common problem in prior art riveting machines, both of a squeeze-vibrate nature and of other natures, is their inability to precisely control the amount of rivet material forming the heads on either side of the rivet. More specifically, in the past it has been conventional to utilize rivet studs of constant diameter, such as those illustrated in U.S. Pat. No. 3,557,442 issued to T. H. Speller for "Slug Riveting Method and Apparatus." Because the rivet stud used in the process and apparatus described in that patent as well as in other processes and apparatus is of constant diameter, the amount of material forming the heads of the resultant rivet, on either side of the panels to be joined, is difficult to control. Because of this difficulty, the uniformity and reliability of such joints is not as great as desired. Moreover, installation time is increased because the rivet stud must be accurately positioned prior to upset.

While some prior art proposals to overcome the previously discussed problems have been made, they have not been entirely satisfactory. One proposal has been to essentially entirely preform one head of the resultant rivet (see U.S. Pat. No. 3,526,032 issued to F. C. Pipher for "Riveting Method Employing Metal Flow in Both the Manufactured Head and the Upset Head"). One problem with this proposal relates to the very limited amount of material that flows in the partially preformed head. Because a limited material flow occurs the rivet studs must be precisely formed. Moreover, the upset force must be precisely applied or else the material flow is inadequate to create a "tight" rivet joint. Further, because the rivet studs must be precisely formed, they are relatively expensive even when mass produced. Hence, this proposal also has several disadvantages.

Another problem with many prior art processes and apparatus is depicted in the Speller patent. Specifically, many prior art processes clamp the panels in position during the period of time that the rivet is being inserted and squeezed to the desired shape, i.e., the riveting steps take place. Because a clamping force is applied to the panels during the riveting steps, there is no assurance that equal forces are applied to both the top and bottom surfaces of the rivet. Rather, unequal forces may be applied and compensated for by the clamp forces. The Speller patent, to some extent, proposes a solution to this problem by providing a lower ram that overcomes the force of the upper clamp and moves the panels and the rivet stud upwardly prior to the termination of upset. However, this solution is not entirely satisfactory because some clamp force remains whereby unequal forces can still be applied to the top and bottom surfaces of the rivet.

Therefore, it is an object of this invention to provide a new and improved riveting process.

It is also an object of this invention to provide a new and improved apparatus for riveting.

It is still a further object of this invention to provide a high fatigue squeeze riveting process wherein rivet joints formed in accordance with the process have improved fatigue life.

It is yet another object of this invention to provide a new and improved riveting process and apparatus for carrying out the process wherein the amount of rivet material forming the heads on either end of the rivet is easy to control and wherein the amount of force prior to the termination of upset is assured to be equally applied to both ends of the rivet.

SUMMARY OF THE INVENTION

In accordance with principles of this invention a high fatigue squeeze riveting process and apparatus for carrying out the process is provided. In accordance with prior art techniques, a pair of panels or the like to be joined are clamped between a pair of clamps and a hole is drilled through the panels. Following creation of the hole, a rivet stud is inserted into the hole. Thereafter, the sequence of steps which form the heart of this invention are carried out. Specifically, rams approach the rivet stud from either end. One ram meets the rivet first and moves the rivet until the rivet achieves a predetermined position in the hole. As force is applied to this ram, the force on the clamp on the same side of the panels is released as the panels are gently pushed away from this clamp. Following release of this clamp, movement of the "pushing" ram ends and the other ram impinges on the other end of the rivet, and applies a squeeze force thereto. As the force applied to the other ram increases, the force applied to the other clamp decreases until, just prior to the termination of upset, the other clamp is also released thereby subjecting the rivet to equal end forces.

In accordance with further principles of this invention, the pre-drilled hole is countersunk on one end. In addition, the rivet stud has two different diameters joined by a conical frustrum shoulder, the larger diameter region forming a partially formed head. Thus, the position of the rivet in the hole is the position at which the shoulder of the rivet mates with the countersink region of the hole.

It will be appreciated from the foregoing brief summary that a new and improved high fatigue maching riveting process and an apparatus for carrying out the process is provided by the invention. It will also be appreciated from the foregoing brief summary that the invention overcomes many of the prior art problems discussed above. For example, upset forces applied to either end of the rivet are assured to be equal. Further, the amount of rivet material forming the heads on either side of the resultant rivet is always the same. In addition, because the head on one side is already partially formed due to the difference in diameters of the rivet studs, the amount of upset force is reduced. Moreover, it has been found that rivet installation time is improved over prior art times. Finally, it has been found in the airframe industry that the fatigue life of rivet joints formed in accordance with the inventive process has been increased by approximately seventy per cent over rivet joints formed in accordance with prior art processes.

It should be noted that while the invention was developed for, and has found its primary use in, the airframe industry its use is not limited to that industry. Rather, the invention is suitable for widespread use in a variety of industries that use riveting to join panels and the like, and desire to improve the fatigue life of rivet joints, and obtain the other benefits of the invention described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing objects and many of the attendant advantages of this invention will become more readily appreciated as the same becomes better understood by reference to the following detailed description when taken in conjunction with the accompanying drawings wherein:

FIG. **1** is a block diagram illustrating, in block form, an apparatus for carrying out the inventive process;

FIG. **2** is an idealized sequence graph illustrating the force sequence applied to the clamps and rams in accordance with the process of the invention;

FIGS. 3A–D are cross-sectional diagrams illustrating clamps and rams and the sequence of movement thereof in accordance with the process of the invention; and,

FIG. **4** is a graph illustrating the application of the combined forces to the clamps and the rams.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **1** is a diagram illustrating, in block form, an apparatus for carrying out the process of the invention which apparatus forms a part of the invention. More specifically, a variety of hydraulic, pneumatic, electro-mechanical etc., structural arrangements could be utilized to form an apparatus in accordance with the invention to carry out the process of the invention. Because the individual structural components necessary to form such an apparatus are well-known in the art, the disclosure of a specific structural arrangement is not illustrated in the drawings and described herein. Rather, the basic machine concept is illustrated in block form and described in general terms.

The apparatus illustrated in block form in FIG. **1** comprises: a master control system **11**; a power supply **13**; an upper clamp **15**; a lower clamp control **17**; an upper ram control **19**; a lower ram control **21**; an upper clamp **23**; a lower clamp **25**; an upper ram **27**; and a lower ram **29**.

The master control **11** includes the basic controls for a mechanical riveting machine. The master control system could be hydraulic or pneumatic, and control the flow of power from the power supply **13** (hydraulic or pneumatic) to the upper and lower clamp controls **15** and **17** and the upper and lower ram controls **19** and **21**. Alternatively, the master control **11** could comprise an electrical control system for controlling the application of electrical power from the power supply **13** (electrical in this case) to electro-mechanical components forming the upper and lower clamp controls **15** and **17**, and the upper and lower ram controls **19** and **21**.

The upper clamp control **15** controls the movement of the upper clamp **23** and the lower clamp control **17** controls the movement of the lower clamp **25** in accordance with the sequence of operation hereinafter described. Similarly, the upper ram control **19** controls the movement of the upper ram **27** and the lower ram control **21** controls the movement of the lower ram **29** in accordance with the sequence of operations hereinafter described.

It will be appreciated from the description thus far that the actual mechanical system for carrying out the process of the invention can take on a variety of forms. Hence, this invention should not be considered as limited to any particular mechanical arrangement.

FIG. **2** illustrates, in idealized form, the application of forces to the upper and lower clamps **23** and **25** and to the upper and lower rams **27** and **29.** For purposes of illustration only forces directed in a downward direction (those applied by the upper clamp and by the upper ram) are illustrated as positive (+) and forces directed in an upward direction (those applied by the lower clamp and by the lower ram) are illustrated as negative (−).

Initially, two panels or other items, herein referred to as the upper **31** and lower **33** panels (FIG. 3A), are brought together and clamped by the upper and lower clamps **23** and **25** in a conventional manner. Preferably, the upper and lower clamps are cylindrical and have aligned cylindrical bores.

After the panels are clamped, by means not illustrated, a hole **35** is drilled through the two panels. The hole is in general alignment with the bores in the clamps and is countersunk at its upper end in the region **37**. Thereafter, by means also not shown, a rivet stud **39** is partially inserted into the hole **35**. All of the foregoing steps occur during the time period $t_0 - t_1$ illustrated in FIG. **2**.

Following the insertion of the rivet stud **39** into the hole **35** the upper and lower rams **27** and **29** are brought into vertical alignment with the bores in the upper and lower clamps **23** and **25** and, thus, into alignment with the central vertical axis of the rivet stud **39.** FIG. 3A illustrates a point in time when the upper ram **27** is applying a force adequate to press the rivet stud **39** through the hole **35.** At about this point in time, the force applied to the upper clamp **23** terminates as the panels **31** and **33** are gently pushed away therefrom by the force applied to the rivet stud via the upper ram **27.** While FIG. **2** illustrates an instantaneous cut-off in the force applied to the upper clamp and an instantaneous application of force applied to the upper ram, it should be recalled that this graph is idealized. Thus, as will be better understood from the following description of FIG. **4**, these force changes are not instantaneous; rather, these force changes occur over a predetermined increment of time.

In any event, as the upper ram **27** moves downwardly it moves the rivet stud **39** through the hole **35** until the rivet stud reaches a predetermined depth of penetration which depth of penetration will be better understood from the following description of the nature of the rivet stud **39.** When the rivet stud **39** has been moved to its predetermined depth of penetration point, downward movement of the upper ram **27** ends and that ram thereafter remains stationary. At this point, as illustrated in FIG. 3B, the panels, as previously described, have been gently pushed away from the upper clamp **23.** The lower panel **33,** however, is still in contact with the lower clamp **25.** Moreover, at this point in the sequence of operation the lower ram **29** has not yet started to impinge on the lower surface of the rivet stud **39,** even though the lower ram may be moving upwardly. Thus, the sequence of operation is still at about t_1 (FIG. **2**), even though some small increment of time has elapsed.

As the lower ram **29** moves upwardly, it eventually impinges on the lower surface of the rivet stud **39** and a squeeze force is applied thereto. As the lower ram continues to move upwardly the amount of squeeze force increases, as illustrated on the lower line of FIG. **2** between t_1 and t_2. Between t_1 and t_2 force, in essence, is transferred from the lower clamp **25** to the lower ram **29** until the force applied to the lower clamp becomes essentially zero and the force applied to the lower ram becomes the entire force applied to the overall structure.

Just prior to the end of upset, between times $t_2 - t_3$, the lower clamp is, preferably, removed from impingement on the lower surface of the lower panel **33** as illustrated in FIG. 3D. Thus, at this point in the sequence, equal forces are applied to both the top and the bottom of the rivet stud **39.**

It will be appreciated that the squeeze (compression) force applied to rivet stud causes the stud to be deformed and rivet heads to be formed in the top and bottom of the rivet in accordance with the nature of the facing surfaces of the upper and lower rams **27** and **29.** As illustrated in FIGS. 3A–D by way of example, the lower ram has a surface that creates a semi-sperical head and the upper ram has a surface that creates a head having a conical depression. However, these head shapes are merely by way of example and other head shapes, as desirable, can be formed.

Subsequent to upset, between times t_3 and t_4, the ram and clamp forces may both be entirely removed, the clamp forces having previously been relaxed as described above, and the panels moved to the next position. Thereafter, the sequence of inventive steps described above reoccurs. Alternatively, the ram force may be removed and the clamp force reapplied. The latter sequence will be followed if surfacing work, such as removal of part or all of the upper head material by a suitable tool, is to be performed. Such work would, for example, occur if the surface of the resultant structure is to be smooth as would be the case if the resultant structure were an aircraft wing, for example.

Turning now to a description of the nature of the rivet stud used by the process and apparatus of the invention; in order for a controlled amount of material to form the heads on either end of the rivet, the rivet stud must be driven to a predetermined depth in the hole **35** prior to the application of squeeze force by the upper and lower rams **27** and **29.** This desired result is accomplished by the use of a novel rivet stud. The rivet stud, as illustrated in FIGS. 3A–D, is formed such that it has an upper diameter that is slightly larger than its lower diameter. These two regions are joined by a conical frustum region. The angle of the conical frustum region is, preferably, the same as the angle of the countersink region **37** of the hole **35.** Thus, the rivet as it is being moved downwardly by the upper ram **27** stops when its conical frustum region (shoulder) mates with or impinges on the surface of the countersink region **37.** At this point, the rivet stud **39** has been driven to the desired depth of penetration. Thereafter, the upper and lower rams compress or upset the rivet stud in the manner previously described.

FIG. **4** is a more exact diagram of the clamp and upset forces applied to the panels **31** and **33** and the rivet stud **39**, respectively, as the steps of the process of the invention proceed to conclusion. The primary difference between FIG. **4** and FIG. **2,** in addition to the fact that FIG. **4** is a more exact replica of the actual forces applied, is that the forces are combined in FIG. **4.** That is, the total clamp forces are illustrated as a single positive force applied to the panels **31** and **33.** In addition, the upset or ram forces applied to the rivet stud **39** are illustrated as a single positive force. Thus, the clamp forces start at a predetermined maximum and drop toward zero while the upset or ram forces start at zero and increase to a predetermined maximum. In addition, FIG. **4** does not depict a zero force during the $t_3 - t_4$ time period. Rather, the $t_3 - t_4$ time period is illustrated as one wherein the clamp force is reapplied in order for further work to be performed prior to panel movement.

It will be appreciated from the foregoing description of a preferred embodiment of the invention that a new and improved high fatigue squeeze riveting process and apparatus for carrying out the process is provided. Actual tests have shown that the fatigue life of a rivet joint formed in accordance with the invention is 70 percent better than prior art rivet joints formed by the squeeze-vibrate process currently being used in the airframe industry. Yet, this improvement results without the use of complicated new machinery or the extensive modification of presently existing machinery. Further, the invention, because of the elimination of vibration, is essentially noiseless when compared to prior art processes using the squeeze-vibrate technique. In addition, the unique process of the invention results in ease of control of the amount of rivet material forming the heads on either side of the resultant rivet. Moreover, rivet joints can be formed more rapidly than they could with prior art apparatus practicing prior art processes. Further, the overall upset force for creating a particular rivet configuration from a particular material is reduced because the entire upset force is applied only to the rivet and not to the surrounding panels. Finally, because, preferably, force is only being applied to the rivet at the termination of upset, the clamp force having been removed prior to termination, the equal application of forces to both sides of the rivet is assured.

While a preferred embodiment of the process and apparatus of the invention has been illustrated and described, it will be appreciated by those skilled in the art and others that various changes can be made therein without departing from the spirit and scope of the invention. For example, in some environments, it may be desirable to maintain a small amount of clamp force during the entire process. Such an environment would exist, for example, if the items to be joined were small in size and, thus, likely to rotate or bend during upset. One method of maintaining an "anti-rotation" or "anti-bending" force is for the lower clamp to maintain contact with the items during the entire upset period. Another method of maintaining an "anti-rotation" force is for a plurality of legs surrounding the upper clamp to come in contact with the items as the items move away from the upper clamp. In addition, other methods can be used as long as they do not interfere with the operation of the invention.

It will also be appreciated that some of the processing steps surrounding the main steps of the invention can vary. For example, the clamping step can occur before or after the items (panels) are moved into position; the drilling of the hole can occur at the same position as the position where the rivet stud is inserted or at a different position; or, a plurality of rivet joints can be formed simultaneously or they can be formed serially (one-after-another). In addition, it will be appreciated that the invention is not limited to joining panels. Rather, it can be used to join any types of items suitable for joining by rivets. Moreover, the clamp and ram forces can be applied in directions other than vertical, as convenient. Finally, one ram can move to position the rivet before the other ram moves at all or both rams can move at the same time as long as the described sequence is followed. Hence, the invention can be practiced otherwise than as specifically described herein.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A high fatigue squeeze riveting process for riveting items together, said items being clamped together by applying suitable opposing clamping forces, one on either side of said items, and including a hole passing through the items, said hole being located adjacent to said clamping forces, said high fatigue squeeze riveting process comprising the steps of:

pressing a rivet stud into said hole from one side thereof until said rivet stud reaches a predetermined depth of penetration in said hole;

removing one clamping force from said items as said rivet stud is pressed into said hole;

applying a force to said rivet stud directly opposite to said pressing direction so as to deform said rivet stud into a rivet; and,

decreasing the other clamping force applied to said items as said rivet stud deforms.

2. A high fatigue squeeze riveting process as claimed in claim **1** wherein said one clamping force is applied to the side of said items from which said rivet stud enters and is pressed into said hole.

3. A high fatigue squeeze riveting process as claimed in claim **2** wherein said items to be riveted together are gently moved away from said one clamping force as said rivet stud reaches its predetermined depth of penetration.

4. A high fatigue squeeze riveting process as claimed in claim **3** wherein said items to be riveted together are moved away from said other clamping force before said rivet stud becomes totally deformed into a rivet.

5. A high fatigue squeeze riveting process as claimed in claim **4** wherein said hole is countersunk to a predetermined depth on the side of said items from which the rivet stud enters and is pressed into said hole.

6. A high fatigue machine riveting process as claimed in claim **5** wherein said rivet stud has two different diameters joined by a conical frustum shoulder.

7. A high fatigue squeeze riveting process as claimed in claim **6** wherein said shoulder of said rivet stud mates with said countersunk region of said hole when said rivet stud reaches its predetermined depth of penetration.

8. A high fatigue squeeze riveting process as claimed in claim **7** wherein said opposing clamping forces surround said hole in said items to be riveted together.

9. A high fatigue squeeze riveting process as claimed in claim **1** wherein said items to be riveted together are moved away from said other clamping force before said rivet stud becomes totally deformed into a rivet.

10. A high fatigue squeeze riveting process as claimed in claim **8** wherein said hole is countersunk to a predetermined depth on the side of said items from which the rivet stud enters and is pressed into said hole.

11. A high fatigue machine riveting process as claimed in claim **9** wherein said rivet stud has two different diameters joined by a conical frustum shoulder.

12. A high fatigue squeeze riveting process comprising the steps of:

clamping together between a pair of clamps items to be riveted together;

drilling a hole through said items to be riveted together adjacent to said pair of clamps;

inserting at least partially a rivet stud into said hole from one side of said items to be riveted together;

pressing said rivet stud through said hole until it reaches a predetermined depth of penetration in said hole;

removing the clamping force applied by said pair of clamps to said one side of said items to be riveted together;

applying a force to said rivet stud opposite to said pressing direction so as to deform said rivet stud into a rivet; and,

removing the clamping force applied by said pair of clamps to the other side of said items as said rivet stud is deformed into a rivet.

13. A high fatigue squeeze riveting process as claimed in claim **12** wherein said items to be riveted together are gently moved away from said clamping force applied by said pair of clamps to said one side of said items to be riveted together prior to the application of said force causing said rivet stud to deform into a rivet.

14. A high fatigue squeeze riveting process as claimed in claim **13** wherein said hole is countersunk on the side through which said rivet stud is inserted and wherein said rivet stud is formed of two different diameters jointed by a conical frustum shoulder.

15. A high fatigue squeeze riveting process as claimed in claim **14** wherein said shoulder of said rivet stud mates with said countersunk region of said hole when said rivet stud reaches its predetermined depth penetration.

16. Apparatus for riveting items together through a hole in said items comprising:

first clamp means including a first clamp located on one side of said items;

second clamp means including a second clamp located on the other side of said items, in alignment with said first clamp;

first ram means including a first ram located on said one side of said items, said first ram being adapted to press a rivet stud into said hole;

second ram means including a second ram located on said other side of said items, in alignment with said first ram;

power supply means for supplying power to said first and second clamp means and to said first and second ram means; and,

control means connected so as to control the application of power to said first and second clamp means and to said first and second ram means in a manner such that:

said first and second clamps initially clamp said items together;

power is rapidly withdrawn from said first clamp as power is rapidly applied to said first ram to press said rivet stud into said hole; and,

power is withdrawn from said second clamp as power is applied to said second ram, said action occurring subsequent to the rapid withdrawal of power from said first clamp and the rapid application of power to said first ram.

17. A high fatigue machine riveting apparatus as claimed in claim **16** wherein said clamps are cylindrical in nature and include aligned central bores, said hole in said items to be riveted being aligned with said aligned central bores in said clamps.

18. A high fatigue squeeze riveting apparatus as claimed in claim **17** wherein said rams are aligned with and pass through the central bores in said clamps.

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