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(54) PIPE CONNECTOR

(57) A connector is provided for interconnecting tubular elements and adapted to be radially expanded. The connector comprises a pin member and a box member, the pin member having a threaded outer surface and the box member having a threaded inner surface so as to allow the pin member to be screwed into the box member. At least one of the threaded outer surface and threaded inner surface is provided with at least one annular recess, wherein each annular recess is provided with a respective annular seal member adapted to swell when in contact with a selected fluid so as to seal said threaded surfaces relative to each other upon swelling of the annular seal member.

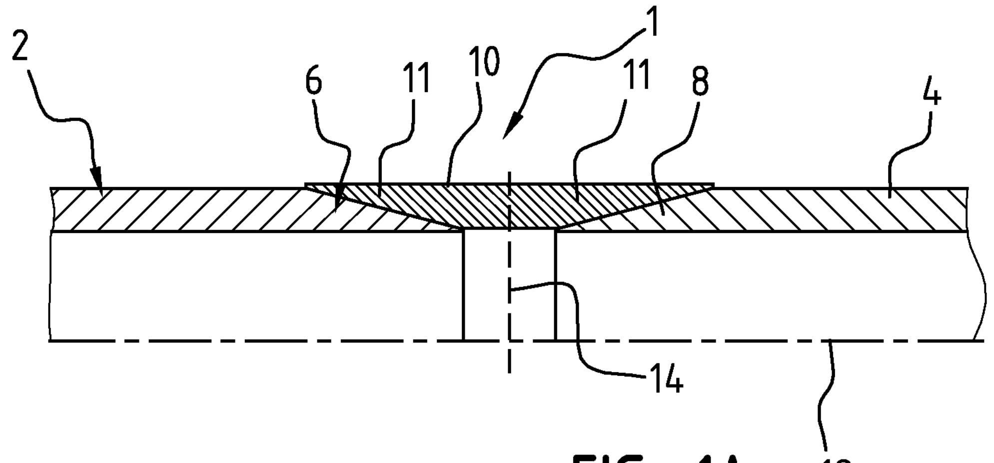


FIG. 1A

EP 2 674 567 A1

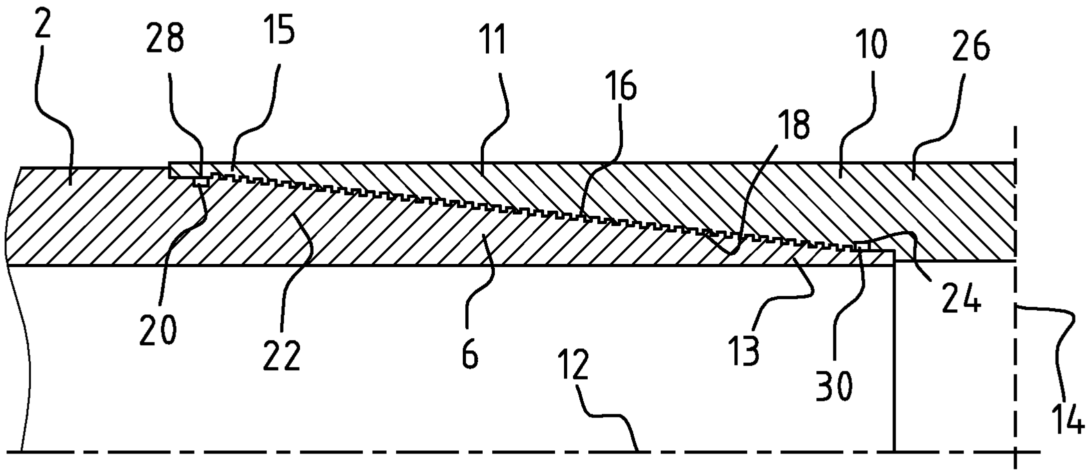


FIG. 1B

Description

[0001] The present invention relates to a connector for connecting tubular elements. The connector comprises a pin member and a box member, the pin member having a threaded outer surface and the box member having a corresponding threaded inner surface to allow the pin member to be screwed into the box member, to form a screwed joint.

[0002] Threaded connectors of this type are generally used in oilfield applications, for instance to connect sections of wellbore casing or production tubing. Often, oilfield applications require the connectors to provide liquid tight and/or gas-tight sealing. Also, the connectors preferably have a strength approximately equal to the body strength of the pipe sections to be connected by the connectors.

[0003] Commonly used connectors are API (American Petroleum Institute) connectors, which include several types of threaded connectors. API connectors conform to specifications as set by the American Petroleum Institute. API connectors generally provide relatively high performance at relatively low cost. However, API connectors may lack adequate or reliable fluid-tight sealing. For instance for applications in reservoirs at a relatively high pressure and/or in relatively deep wellbores. In particular after radial expansion of the pipe and the connector, the API connectors may not be fluid-tight. Moreover, API connectors typically require expansion forces exceeding the expansion forces required to expand the corresponding pipes.

[0004] In view thereof there is a need to provide an improved connector for applications wherein fluid-tight sealing is required.

[0005] WO-01/04520 discloses a connector for interconnecting tubular elements and adapted to be radially expanded. The connector comprises a pin member and a box member, the pin member having a threaded outer surface and the box member having a correspondingly threaded inner surface, allowing the pin member to be made-up in the box member. The threaded inner surface of the box member is provided with an annular recess comprising an elastomeric seal ring and a separate spacer ring.

[0006] It is an object of the invention to provide an improved connector which overcomes the drawbacks of the prior art.

[0007] The present invention therefore provides a connector for connecting adjoining tubular elements, comprising:

a pin member having a threaded outer surface;
a box member having a threaded inner surface corresponding to the threaded inner surface of the pin member, allowing the pin member and the box member to make-up a threaded connection,
wherein at least one of the threaded outer surface and threaded inner surface is provided with at least one annular recess, and
wherein said at least one annular recess is provided with a respective annular seal member adapted to swell when in contact with a selected fluid to seal said threaded outer surface relative to said threaded inner surface upon swelling of the annular seal member.
When the annular seal member contacts the selected fluid, the annular seal member swells and thereby seals the threaded outer surface of the pin member relative to the threaded inner surface of the box member. The fluid is selected to be the fluid susceptible of being in contact with the annular seal during normal operation of the connector and pipe assembly.

[0008] In an embodiment, the fluid may be selected from the group of hydrocarbons and water.

[0009] In another embodiment, the connector is adapted to be radially expanded.

[0010] In an embodiment, said at least one annular recess includes a first annular recess provided with a first annular seal member and a second annular recess provided with a second annular seal member, wherein the first annular recess and the second annular recess are arranged at opposite ends of said threaded connection. The seal members prevent fluid at the interior or exterior of the connector from migrating between the engaged threaded surfaces.

[0011] Optionally, the threaded outer surface of the pin member tapers radially inward and the threaded inner surface of the box member tapers in corresponding manner, wherein the first annular recess is formed in a base section of the threaded outer surface of the pin member, and wherein the second annular recess is formed in a base section of the threaded inner surface of the box member. This minimizes the influence of the recesses on the mechanical integrity of the connector.

[0012] Preferably, the first and second annular seal members is adapted to swell when in contact with a fluid present at the exterior of the connector, and wherein the second annular seal member is adapted to swell when in contact with a fluid present at the interior of the connector.

[0013] The pin member may have a critical cross-sectional area defined as the cross-sectional area where the equivalent stress in the pin member is highest when the connector is axially loaded, wherein the box member has a critical cross-sectional area defined as the cross-sectional area where the equivalent stress in the box member is highest when the connector is axially loaded, and wherein said critical cross-sectional areas are selected such that said highest equivalent stress in the pin member is substantially equal to said highest equivalent stress in the box member. This will minimise the expansion force required to radially expand the connector.

[0014] Preferably the ratio of the critical cross-sectional area of the pin member to the critical cross-sectional area of the box member is substantially equal to one.

[0015] Suitably the pin member is connected to one of said tubular elements and the box member is connected to another one of said tubular elements, wherein the connector has an axial strength defined as the maximum axial load the connector can sustain without plastic deformation of at least one of the pin member and the box member, wherein said tubular elements have an axial strength defined as the maximum axial load the tubular elements can sustain without plastic deformation of at least one of the tubular elements, and wherein the axial strength of the connector is substantially equal to the axial strength of the tubular elements. In this manner a difference between a connector expansion force required to expand the connector and a pipe expansion force required to expand the tubular elements is minimised or eliminated.

[0016] When the connector is subjected to an axial tensile load, said axial tensile load may be transmitted between the pin member and the box member via a back surface of the thread of the pin member and a corresponding back surface of the thread of the box member, and wherein said back surface and corresponding back surface extend substantially perpendicular to the axial direction of the connector. This increases the axial tensile strength of the connector.

[0017] When the connector is subjected to an axial compressive load, said axial compressive load may be transmitted between the pin member and the box member via a front surface of the thread of the pin member and a corresponding front surface of the thread of the box member, and wherein said front surface and corresponding front surface extend substantially perpendicular to the axial direction of the connector. This increases the axial compressive strength of the connector.

[0018] Suitably the box member has an end portion of relatively small wall thickness, and wherein the end portion of relatively small wall thickness is connected to the pin member so as to prevent radial separation of the end portion of relatively small wall thickness from the pin member during or after radial expansion of the connector.

[0019] Suitably radial separation of said end portion of relatively small wall thickness from the pin member is further prevented if the end portion of relatively small wall thickness is connected to the pin member by soldering or brazing.

[0020] The invention will be described hereinafter by way of example, with reference to the accompanying drawings in which:

Fig. 1a schematically shows a longitudinal section of an embodiment of a connector according to the invention;
Fig. 1b schematically shows a detail of the connector of Fig. 1a;
Fig. 2 schematically shows a longitudinal section of a prior art connector as a starting point in an optimisation method used in conjunction with the invention;
Fig. 3 schematically shows a in longitudinal section of a connector considered in a first step of the optimisation method;
Fig. 4 schematically shows a longitudinal section of a connector considered in a second step of the optimisation method;
Fig. 5 schematically shows a longitudinal section of a connector considered in a third step of the optimisation method;
Fig. 6 schematically shows a longitudinal section of a connector considered in a fourth step of the optimisation method;
Fig. 7 schematically shows a longitudinal section of a detail of the connector of Fig. 6;
Fig. 8 schematically shows a longitudinal section of a connector considered in a fifth step of the optimisation method;
Fig. 9 schematically shows a longitudinal section of an expansion cone and a tubular element being radially expanded with the expansion cone;
Fig. 10 shows a cross-section of an exemplary threaded surface;
Fig. 11 shows a cross-section of an exemplary threaded surface of an API connector; and
Fig. 12 shows a cross-section of an exemplary threaded surface of a connector according to the invention.

[0021] Expansion tests have been performed on a conventional API buttress connector for interconnecting 7 5/8 inch 29.71b/ft LSX80 pipe. This pipe was expanded together with the connector in fix-free condition which is a condition whereby one end of the pipe and connector assembly is fixed and the other end is free to move in axial direction during radial expansion of the assembly. Two types of connectors were used, one having an outer diameter (OD) of 8.5 inch and the other having an outer diameter (OD) of 8.07 inch. The obtained results are shown in Table 1 indicating the following parameters: E.R. $_{=}$ expansion ratio of the pipe and connector $F_{exp\ body}$ = expansion load of the pipe body $F_{exp\ total}$ = expansion load of the connector/pipe assembly $F_{yield\ body}$ = yield strength of the pipe $A_{cr\text{-}box}$ = critical cross-sectional area of the box member $A_{cr\text{-}pin}$ = critical cross-sectional area of the pin member.

[0022] The critical cross-sectional area of the box member is considered to be the cross-sectional area of the full body of the box member since there is full load transfer from the pipe to the box member. The critical cross-sectional area of the pin member is considered to be the cross-sectional area of the full body of the pipe since there is full load transfer from the connector to the pipe. The ratio of the critical cross-sectional area of the box member to the critical cross-sectional area of the pin member expresses the mechanical integrity of the connector and pipe assembly. When this ratio is equal to one the connector is as strong as the pipe. If it is higher (lower) the connector is stronger (weaker) than the pipe. In this context, mechanical integrity means the ability of the connector and pipe configuration to carry high expansion, tension and compression loads. The ratio $F_{exp\ total} / F_{exp\ body}$ expresses the extra force required to expand the connector and pipe configuration relative to the expansion force required to expand the pipe only. The ratio $F_{yield\ body} / F_{exp\ total}$ provides information as to whether or not the pipe will yield during the expansion process.

[0023] The results relating to the 8.5 inch OD connector and 27% pipe expansion show that F_{exp} total is significantly higher than $F_{exp\ body}$ (the ratio F_{exp} total / $F_{exp\ body}$ = 2.5). This is due to the relatively large difference between the wall thicknesses of the pipe and the connector, hence relatively large difference between the critical areas of the pipe and the connector. More precisely, the ratio of critical connector area to critical pipe area is 1.75. Moreover, $F_{exp\ total}$ is higher than the pipe strength since the ratio $F_{yield\ body} / F_{exp\ total}$ is smaller than one. Nevertheless, the fix-free expansion was successful since neither the pipe nor the connection failed during the test. This is mainly due to the fix-free condition which is a less severe expansion condition than a fix-fix expansion condition, the latter being a condition whereby the positions of the ends of the pipe and connector assembly are fixed so that the assembly cannot axially shorten during radial expansion.

[0024] The results relating to the 8.07 inch OD connector and 16% pipe expansion show that $F_{exp\ total}$ is 1.82 times F_{exp} body which is still too high despite the fact that the ratio of the critical areas of pipe and connector is equal to one. The ratio of $F_{yield\ body}$to F_{exp} total is greater than one which means that $F_{exp\ total}$ is lower than $F_{yield\ body}$. The results relating to the 8.07 inch OD connector and 27% pipe expansion show that $F_{exp\ total}$ is 1.88 times $F_{exp\ body}$. Moreover, $F_{exp\ total}$ exceeds the pipe strength since the ratio $F_{yield\ body} / F_{exp\ total}$ is 0.72.

[0025] It can be concluded that a relatively large difference between the critical cross-sectional area of the box member and the critical cross-sectional area of the pipe results in a relatively large difference between $F_{exp\ body}$ and $F_{exp\ total}$. In view thereof the difference between these critical areas pipe should be minimized in order to minimize the difference between $F_{exp\ body}$ and F_{exp} total. Nevertheless, there is a limitation on how close the critical areas of connector and pipe can be brought since an OD reduction in the connector may compromise the mechanical integrity of the connector. Moreover, from the aforementioned results it was observed that for high expansion ratios of the pipe, $F_{exp\ total}$ is higher than the pipe strength, which is undesirable as it can lead to failure of the pipe.

Table 1.

Connector OD (inch)	E.R. (%)	Critical connector area / critical pipe area	$F_{exp\ body}$ (MN)	F_{exp} total (MN)	$F_{yield\ body}$ (MN)	F_{exp} total/ $F_{exp\ body}$	$F_{yield\ body}$/ F_{exp} total
8.50	27	1.75	1.00	2.50	1.4	2.50	0.56
8.07	16	1.00	0.65	1.18	1.4	1.82	1.18
8.07	27	1.00	1.00	1.88	1.4	1.88	0.75

[0026] In order to overcome the drawbacks related to expansion of the API connector, a method is provided to optimise a connector with regard to expandability whereby the connector is scaled up or down to any desired size. The method is explained hereinafter in more detail.

[0027] The optimisation method comprises a number of steps whereby in each optimisation step a characteristic of the connector is varied and the mechanical integrity of the connector is tested by finite element analysis both before and after expansion of the connector. In an exemplary embodiment of the method, a standard API buttress connector for 7 5/8 inch 291b/ft VM50 pipe is used as a starting point in the method. This connector has all the disadvantages in respect of expandability mentioned hereinbefore. In a first optimisation step the connector is scaled up by keeping the ratio of pipe wall thickness to thread length constant. The resulting connector requires very high expansion forces relative to the expansion forces required to expand the pipe body. Therefore, in a further optimisation step the outer diameter of the box member is reduced, resulting in a connector having high mechanical integrity after expansion. In view thereof, the OD of the box member is even further reduced so that the connector is externally and internally flush and has strength after expansion close to the strength of the pipe after expansion. However a drawback of this connector is that the box member bends radially outward after expansion. To resolve this issue, some threads near the end of the box member are removed and a solder layer is introduced instead. Moreover, in that design the engaged threaded surfaces of the pin member and box member are sealed relative to each other by annular seal members whereby a first seal member is arranged in an annular recess provided in the pin member and a second seal member is arranged in an annular recess provided in the box member. The first seal member is made of a material that swells when in contact with a fluid present at the exterior of the connector, and the second seal member is made of a material that swells when in contact with a fluid present at the interior of the connector. In a next optimisation step the length of the solder layer is decreased and its thickness is increased to strengthen the solder somewhat. In a further optimisation step the geometry of the expansion cone for expanding the connector, is optimised in order to avoid inward bending of the end portion of the pin member and insufficient thread support that may compromise the mechanical strength of the connector after expansion. Optimisation of the expansion cone is explained hereinafter in more detail. To improve the compression strength of the connector and to reduce even further inward bending of the end portion of the pin member, a further solder layer is provided between the end portion of the pin member and the box member.

[0028] The connector designs so far can be quite long due to the large number of threads required to guarantee high mechanical integrity. Nevertheless, the threads at the end portion of the pin member and the threads at the end portion of the box member hardly contribute to the mechanical integrity of the connector due to the limited wall thickness at said end portions. Therefore, in a next optimisation step these threads are removed by increasing the taper of the threaded surfaces of the pin and box members from 6.25% to 8%. The failure mode in axial compression and axial tension of all the aforementioned connectors is thread separation due to sliding of the thread surfaces of the pin and box members relative to each other. To mitigate this phenomenon for axial tensile loading, in a yet further optimisation step the back angle of the threads is reduced to zero. To mitigate this phenomenon for axial compressive loading, the front angle of the threads is reduced to zero.

[0029] Hereinafter, like reference signs relate to like components.

[0030] Figs. 1A, 1B show a longitudinal section of a connector 1 for connecting a first tubular element 2 to a second tubular element 4, having a central longitudinal axis 12. The connector 1 comprises a first pin member 6 integrally formed with the first tubular element 2. A second pin member 8 is integrally formed with the second tubular element 4. A cylindrical connecting element 10 is at two opposite ends provided with a box member 11. In the embodiment of Fig. 1a, the connector 1 has an axis of symmetry 14. As the connector is symmetrical, hereinafter only the part of the connector 1 shown on the left of axis 14 will be described.

[0031] As shown in Fig. 1B, the pin member 6 has a threaded outer surface 16. The box member 11 has a threaded inner surface 18. The respective threads of the threaded surfaces 16, 18 correspond to each other to allow the pin member 6 to be screwed into the box member 11, to make up a threaded connection (Fig. 1B). The threaded outer surface 16 of the pin member tapers from a pin base section 22 having a relatively large outer diameter to an end section 13 having a smaller outer diameter. The wall thickness of the pin member decreases starting from the pin base section 22 towards the pin end section 13. The threaded inner surface 18 of the box member 11 tapers in corresponding manner, from a box base section 26 having a wall thickness about equal to the wall thickness of the cylindrical body 10 towards a box end section 15 having a thinner wall.

[0032] The threaded outer surface 16 of the pin member may be provided with a first annular recess 20. The recess 20 may be formed in the pin base section 22. The threaded inner surface 18 of the box member may be provided with a second annular recess 24, which may be formed in the box base section 26. A first annular seal member 28 may be arranged in the first annular recess 20. A second annular seal member 30 may be arranged in the second annular recess 24. The annular seal members 28, 30 may comprise a material which swells when in contact with a predetermined fluid. Said fluid may be selected from hydrocarbons or water.

[0033] The first annular seal member 28 may be made of a material adapted to swell when in contact with a fluid that, during intended use, will be present at the exterior of the connector 1. The second annular seal member 30 may be made of a material adapted to swell when in contact with a fluid that, during intended use, will be present at the interior of the connector 1. For example, if the connector is used to connect two tubing sections in a wellbore, the fluid present at the outside of the connector may be brine. The fluid present at the inside of the connector may be crude oil. A suitable material for the annular seal member 28 may be an elastomer that swells when in contact with water, and a suitable material for the annular seal member 30 may be an elastomer that swells when in contact with oil. Other combinations may be conceivable. Also, at least one annular seal may comprise both an elastomer that swells in hydrocarbons and an elastomer that swells in water.

[0034] Suitable swellable materials to be comprised in the seals may include one or more of swelling rubbers, elastomers or clay. Swelling herein may indicate that the material of which the particles are made will swell when contacted with a certain fluid, such as water or hydrocarbons. If the seals swell, the fluid tightness of the connector 1 will improve over time. The amount of swell of the seals during introduction in the wellbore is preferably kept to a minimum, for instance 0% to 10% swell in volume. The swelling of the seals when contacted with the selected fluid is preferable larger than the swell during placement, for instance 100-200% or more swell in volume. For suitable materials, reference is made to for instance US-7578347. The elastomer may include a Super Absorbent Polymer, such as sodium polyacrylate, polyacrylamide, mixtures thereof and/or cross-linked products thereof.

[0035] Figs. 2-8 relate to various stages of a method of optimising a connector in respect of expandability. Similarly to the connector shown in Figs. 1a, 1b, the connector considered in the optimisation method has a box member and a pin member. Herein, box member may be symmetrical, having a box member at each end each corresponding to a respective pin member, wherein each pin member is integrally formed with a respective tubular element. The optimisation method is used to scale up or down a connector to any pipe size desired. The following parameters are used, whereby the subscript (i) refers to a respective stage of the optimisation method:

- IDp_i = inner diameter pin member;
- ODp_i = outer diameter pin member;
- IDb_i = inner diameter box member;
- ODb_i = outer diameter box member;
- tb_i = thickness of the box member at the small diameter end of the threaded surface of the box member;
- L_i = axial length of the engaged threaded surfaces of the pin and box members;
- R_{iu} = ratio of the axial strength (tensile or compressive) of the unexpanded connector to the axial strength (tensile or compressive) of the tubular elements to be interconnected; and
- R_{ie} = ratio of the axial strength (tensile or compressive) of the expanded connector to the axial strength (tensile or compressive) of the tubular elements to be interconnected.

[0036] Fig. 2 shows a conventional API connector, indicated by reference sign A, having a pin member 32 and a box member 34. The connector A is considered as a starting point and has the following characteristics:
IDp = 6.875 inch; ODp = 7.625 inch;
IDb = 7.204 inch; ODb = 8.5 inch; and
tb = 0.603 inch; L = 3.1968 inch.

[0037] Referring to Fig. 3, in a first step of the optimisation method the connector A is modified by increasing the inner diameter of the box member in order to reduce the critical cross-sectional area of the box member relative to the critical cross-sectional area of the pin member. Herein, "critical cross-sectional area" implies the cross-sectional area where the highest stresses occur when the connector is subjected to axial loading, which is normally at the cross-section where the full axial load is transferred. For the pin member this will generally be at the cross-section where the diameter of the threaded outer surface is largest. For the box member this will generally be at the cross-section where the diameter of the threaded inner surface is smallest. By modifying the connector in this manner, a connector B is obtained having pin member 36 and box member 38. Connector B has the following characteristics:
IDp_1 = 6.875 inch; ODp_1 = 7.625 inch;
IDb_1 = 7.294 inch; ODb_1 = 8.5 inch; and
tb_1 = 0.603 inch; L_1 = 3.1968 inch.

[0038] Referring to Fig. 4, in a second step of the optimisation method the connector B is modified by reducing the outer diameter of the box member in order to further reduce the ratio of the critical cross-sectional area of the box member to the critical cross-sectional area of the pin member. A connector C is obtained having pin member 40 and box member 42. Connector C has the following characteristics:
IDp_2 = 6.875 inch; ODp_2 = 7.625 inch;
IDb_2 = 7.294 inch; ODb_2 = 8.05 inch;
tb_2 = 0.378 inch; L_2 = 3.1968 inch.

[0039] Referring further to Fig. 5, in a third step of the optimisation method the connector C is further modified by reducing the outer diameter of the box member and increasing the inner diameter of the pin member so as to increase the axial strength of the engaged threaded surfaces relative to the axial strength of the tubular elements to be interconnected. This further modification results in a connector D with pin member 44 and box member 46. Connector D has the following characteristics:
IDp_3 = 7.144 inch; ODp_3 = 7.625 inch;
IDb_3 = 7.294 inch; ODb_3 = 7.838 inch;
tb_3 = 0.272 inch; L_3 = 3.1968 inch.

[0040] Then the ratio R_u of the axial strength of the connector D in unexpanded state, to the axial strength of the tubular elements to be interconnected, is determined. Also the ratio R_e of the axial strength of the connector D in expanded state, to the axial strength of the tubular elements to be interconnected, is determined. Next, the connector D is scaled up or down to the desired size whereby the ratio of the wall thickness of the tubular elements to be interconnected, to the length of the engaged threaded surfaces, is kept constant. After scaling the connector D, the ratios R_u and R_e are again determined. If the ratios R_u and R_e after scaling the connector are similar to the ratios R_u and R_e before scaling the connector, the optimisation method is finalised. If R_u after scaling the connector is smaller than R_u before scaling the connector, and/or R_e after scaling the connector is smaller than R_e before scaling the connector, the optimisation method is continued.

[0041] Referring further to Fig. 6, in a fourth step of the optimisation method the length of the threaded surfaces is increased by decreasing the taper angle of the threaded surfaces. A connector E is thereby obtained having pin member 48 and box member 50. Reference numeral 52 indicates the engaged threaded surfaces before decreasing the taper angle and reference numeral 54 indicates the engaged threaded surfaces after decreasing the taper angle. The ratio

R_u of the axial strength of the connector E in unexpanded state, to the axial strength of the tubular elements to be interconnected, is determined. Also the ratio R_e of the axial strength of the connector E in expanded state, to the axial strength of the tubular elements to be interconnected, is determined. If these ratios are similar to the corresponding ratios of connector D before scaling up or down, the optimisation method is finalised. If R_u of connector E is smaller than R_u of connector D before scaling up or down, and/or R_e of connector E is smaller than R_e of connector D before scaling up or down, the optimisation method is continued.

[0042] Referring further to Figs. 7 and 8, in a fifth step of the optimisation method the thread of the threaded surfaces is scaled down. For instance, the pitch of the thread is decreased and/or the height of the individual threads is decreased. Scaling down the threads increases the axial strength of the threaded connection.

[0043] Fig. 7 shows the connector E, i.e. before scaling down of the thread, with pin member 48 and box member 50 having a relative coarse thread. As shown in Fig. 8, after scaling down of the thread a connector F is obtained with pin member 56 and box member 58 having a relative fine thread. Then the ratio R_u of the axial strength of the connector F in unexpanded state, to the axial strength of the tubular elements to be interconnected, is determined. Also the ratio R_e of the axial strength of the connector F in expanded state, to the axial strength of the tubular elements to be interconnected, is determined. If these ratios are similar to the corresponding ratios of connector D before scaling up or down, the optimisation method is finalised. If R_u of connector F is smaller than R_u of connector D before scaling up or down, and/or R_e of connector F is smaller than R_e of connector D before scaling up or down, the optimisation method is continued.

[0044] A practical embodiment of a connector optimised using the method of the present invention is for instance shown in Figure 12. For comparison, Fig. 11 shows a typical API connection. The pitch of the thread of the API connection (Fig. 11) is about 5.08 mm. In the connector of the invention, the pitch is reduced to about 2.5 mm (Fig. 12). The pitch may be reduced to about 75% or less of the pitch of the API thread. The height of the tread of the API connector is about 1.565 mm. In the connector of the invention, the height of the thread is reduced to about 0.8 mm (Fig. 12). The height may be reduced to about 75% or less of the height of the API thread.

[0045] In a sixth step of the optimisation method, the front angle of the thread is decreased and/or the back angle of the thread is reduced. Herein, "front angle" means the angle α (Fig. 11) formed between the front surface 79 of the thread 77 and the radial direction 12 (Fig. 10). The front surface of the thread transmits axial compressive loads between the pin member and the box member. By "back angle" is meant the angle β (Fig. 11) formed between the back surface 78 of the thread and the radial direction 12 (Fig. 10). The back surface 78 of the thread transmits axial tensile loads between the pin member 6 and the box member.

[0046] The taper angle, as referenced with respect to Fig. 6 above, can be defined as the angle between centreline 12 of the connector and thread line 76 (Fig. 11). The thread line is for instance parallel to the top surface of the threads 77.

[0047] The front angle α and back angle β of the threads 77 of a conventional API connector (Fig. 11) are about 10 degrees for the front angle α and about 3 degrees for the back angle β.

[0048] In the sixth step, suitably both the front angle α and the back angle β of the threads are reduced with respect to the API connector. Optimal results have been achieved when both the front angle α and the back angle β of the threads are reduced to about zero degrees (Fig. 12).

[0049] An analysis was performed regarding the connectors A-F described above, whereby an expansion ratio of 23% of the pipe and connector was taken into account, with fix-fix conditions of the pipe and connector assembly. The term "fix-fix condition" means a condition whereby axial shortening of the assembly due to radial expansion is suppressed. A purpose of the analysis was to find a balance between mechanical integrity and reduction of maximum forces of connector and pipe during expansion. The ratio of the critical cross-sectional area of the box member, to the critical cross-sectional area of the pin member was kept close to one, but higher than one since the box member should be at least as strong as the pipe. Table 2 below shows results of the analysis for the ratio $A_{cr\text{-}box} / A_{cr\text{-}pin}$ wherein $A_{cr\text{-}box}$ is the critical cross-sectional area of the box member and $A_{cr}\text{-}p_{in}$ is the critical cross-sectional area of the pin member, the ratio $F_{exp\ total} / F_{exp\ body}$ wherein $F_{exp\ total}$ is the expansion load of the connector - pipe assembly and $F_{exp\ body}$ is the expansion load of the pipe body, and the ratio $F_{yield\ body} / F_{exp\ total}$ wherein $F_{yield\ body}$ is the yield strength of the pipe.

[0050] It was found that the connector A has the highest value of the ratio $A_{cr\text{-}box} / A_{cr\text{-}pin}$, the highest value of the ratio $F_{exp\ total} / F_{exp\ body}$ and the lowest value of the ratio $F_{yield\ body} / F_{exp\ total}$. By increasing the inner diameter of the box member, thereby reducing the wall thickness of the box member, the ratio $A_{cr\text{-}box} / A_{cr\text{-}pin}$ is reduced (connector B). However the reduced wall thickness has no effect on the ratios $F_{exp\ total} / F_{exp\ body}$ and $F_{yield\ body} / F_{exp\ total}$ since $F_{exp\ total}$ depends on the total wall thickness of the pin and box members together. For connectors A and B this total wall thickness is the same.

[0051] In connector C the outer diameter of the box member is reduced from 8.5 inch to 8.05 inch. This results in a reduction of the ratios $A_{cr\text{-}box} / A_{cr\text{-}pin}$, $Fe_{xp\ total}\ F_{exp\ body}$ and an increase of $F_{yield\ body}\ F_{exp\ total}$. In connectors D and E the box member is strengthened relative to the pipe by properly adjusting the wall thicknesses of the pipe and box member. This results in a further reduction of difference between F_{exp} total and $F_{exp\ body}$ and also a reduction of difference between $F_{yield\ body}$ and $F_{exp\ total}$.

[0052] Connectors D and E have equal values for $F_{exp\ total}$ because there is no difference between pin thickness and box member thickness.

[0053] The above analysis revealed that by properly adjusting the geometry of pipe and connector it is possible to reduce the forces required to expand the connector while maintaining an acceptable level of mechanical integrity. Furthermore, in this manner the expansion process is made more stable since the difference between $F_{yield\ body}$ (yield strength of the pipe) and $F_{exp\ total}$ (expansion load of the pipe and connector assembly) is increased.

Table 2.

Case	$A_{cr\text{-}box}$ / $A_{cr\text{-}pin}$	$F_{exp\ total}/F_{exp\ body}$	$F_{yield\ body}/F_{exp\ total}$
connector A	1.871	2.40	1.100
connector B	1.752	2.40	1.100
connector C	1.067	1.64	1.610
connector D	1.159	1.51	1.827
connector E	1.159	1.51	1.827
connector F	1.159	1.51	1.827

[0054] Fig. 9 shows an expansion cone and a tubular element during expansion with the expansion cone. Herein, seven optional optimisation parameters for the expansion cone are indicated. Optimisation of the expansion cone can be desired, for example, to avoid inward bending of the end portion of the pin member and insufficient thread support that may compromise the mechanical strength of the connector after expansion. The mechanical strength and sealability of a connector after expansion depends strongly on the expansion ratio and the shape of the expansion cone. For a given connector and expansion ratio, the expansion cone can be optimised using finite element simulations. This optimisation method evaluates the cone shape performance during expansion by monitoring pipe surplus, i.e. expansion of the pipe to a larger diameter than the cone diameter, inward movement of the tip of the pin due to elastic spring back and thread separation during and after expansion. The objective of the optimisation method is to select an optimal cone shape for providing optimal conditions for sealing of the connection after expansion and keeping the mechanical strength of the connection unchanged or improved.

[0055] The shape of the expansion cone can be defined and a model can be drawn using a maximum of seven parameters, including one or more of length 60 of the nose cylindrical section, nose fillet radius 62, maximum cone angle 64, length of the section of maximum cone angle 68, round-off radius 66, outer diameter of the cone 70 and length of the gauge section of the cone 71. An algorithm is used to automatically generate a number of cone models by retrieving the six parameters from a database. The database is prepared by providing a range of values for the abovementioned parameters. The cone models are then used to numerically simulate the expansion process for a given connection design. The simulation output includes pipe surplus, pin tip spring back, threads separation and separation box tip sealing area from the pin. These outputs are plotted versus the cone round off radius, and for each cone angle. Trends of output values are evaluated and an iterative simulation loop is used to concentrate the investigation in the range of parameter values of interest, such that pipe surplus is maximised and pin spring back and thread separation and separation at sealing areas are minimised. The optimisation method results in an optimal cone shape for a given connection to provide optimal mechanical strength and sealability after expansion.

[0056] The present invention is not limited to the exemplary embodiments thereof described above, wherein many modifications are conceivable within the scope of the appended claims. For instance, features of embodiments may be combined.

Claims

1. A connector for connecting tubular elements, comprising:

a pin member having a threaded outer surface;
a box member having a threaded inner surface corresponding to the threaded inner surface of the pin member, allowing the pin member and the box member to make-up a threaded connection,
wherein at least one of the threaded outer surface and threaded inner surface is provided with at least one annular recess, and
wherein said at least one annular recess is provided with a respective annular seal member adapted to swell when in contact with a selected fluid to seal said threaded outer surface relative to said threaded inner surface

upon swelling of the annular seal member.

2. The connector of claim 1, being adapted to be radially expanded.

3. The connector of claim 1, wherein said at least one annular recess includes a first annular recess provided with a first annular seal member and a second annular recess provided with a second annular seal member, and wherein the first annular recess and the second annular recess are arranged at opposite ends of said threaded connection.

4. The connector of claim 3, wherein the threaded outer surface of the pin member tapers radially inward and the threaded inner surface of the box member tapers in corresponding manner,
wherein the first annular recess is formed in a base section of the threaded outer surface of the pin member, and wherein the second annular recess is formed in a base section of the threaded inner surface of the box member.

5. The connector of claim 3, wherein the first annular seal member is adapted to swell when in contact with a fluid present at the exterior of the connector, and wherein the second annular seal member is adapted to swell when in contact with a fluid present at the interior of the connector.

6. The connector of claim 1,
wherein the pin member has a critical cross-sectional area defined as the cross-sectional area where the equivalent stress in the pin member is highest when the connector is axially loaded,
wherein the box member has a critical cross-sectional area defined as the cross-sectional area where the equivalent stress in the box member is highest when the connector is axially loaded, and
wherein said critical cross-sectional areas are selected such that said highest equivalent stress in the pin member is substantially equal to said highest equivalent stress in the box member.

7. The connector of claim 6, wherein the ratio of the critical cross-sectional area of the pin member to the critical cross-sectional area of the box member is substantially equal to one.

8. The connector of claim 1,
wherein the pin member is connected to one of said tubular elements and the box member is connected to another one of said tubular elements,
wherein the connector has an axial strength defined as the maximum axial load the connector can sustain without plastic deformation of at least one of the pin member and the box member,
wherein said tubular elements have an axial strength defined as the maximum axial load the tubular elements can sustain without plastic deformation of at least one of the tubular elements, and
wherein the axial strength of the connector is substantially equal to or larger than the axial strength of the tubular elements.

9. The connector of claim 1,
wherein when the connector is subjected to an axial tensile load, said axial tensile load is transmitted between the pin member and the box member via a back surface of the thread of the pin member and a corresponding back surface of the thread of the box member, and wherein said back surface and corresponding back surface extend substantially perpendicular to the axial direction of the connector.

10. The connector of claim 1, wherein when the connector is subjected to an axial compressive load, said axial compressive load is transmitted between the pin member and the box member via a front surface of the thread of the pin member and a corresponding front surface of the thread of the box member, and wherein said front surface and corresponding front surface extend substantially perpendicular to the axial direction of the connector.

11. The connector of claim 1, wherein the box member has an end portion of relatively small wall thickness, and wherein the end portion of relatively small wall thickness is connected to the pin member so as to prevent radial separation of the end portion of relatively small wall thickness from the pin member during or after radial expansion of the connector.

12. The connector of claim 1, wherein the pin member has an end portion of relatively small wall thickness, and wherein the end portion of relatively small wall thickness is connected to the box member so as to prevent radial separation of the end portion of relatively small wall thickness from the box member during or after radial expansion of the

connector.

13. The connector of claim 1, wherein the threaded section on the box member is connected to the threaded section on the pin member so as to prevent radial separation of the pin threads and the box threads during or after radial expansion of the connector.

14. The connector of claim 10, wherein the end portion of relatively small wall thickness is connected to the pin member by soldering or brazing.

15. The connector of claim 12 or 13, wherein the end portion of relatively small wall thickness is connected to the box member by soldering or brazing.

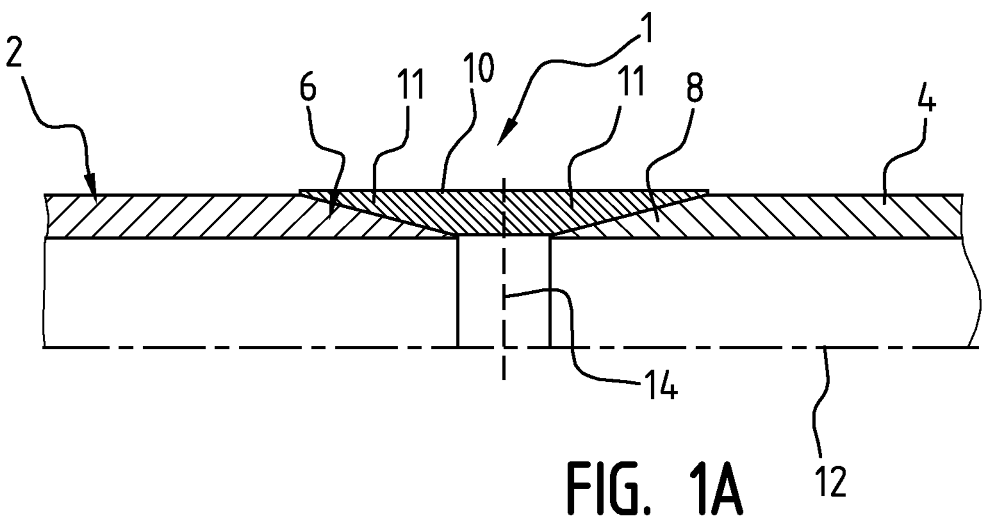


FIG. 1A

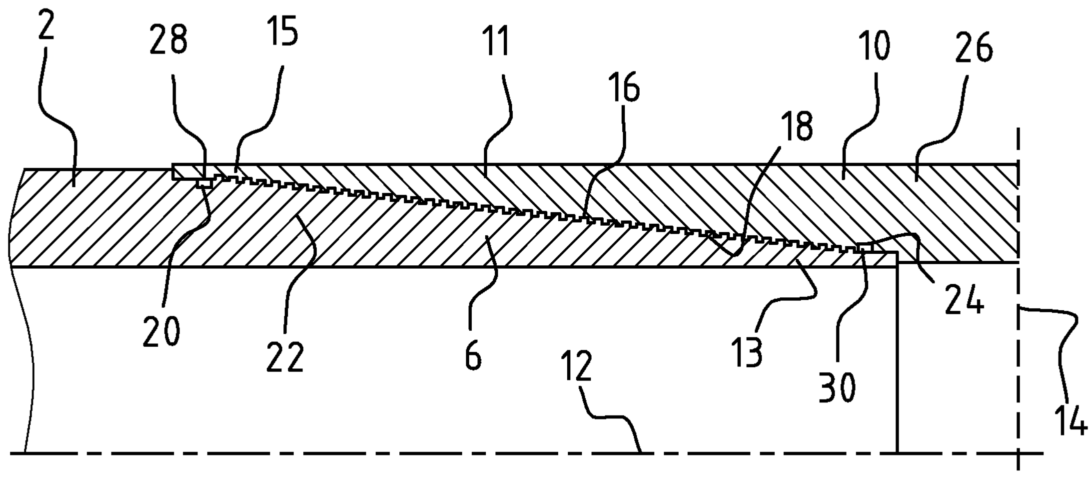


FIG. 1B

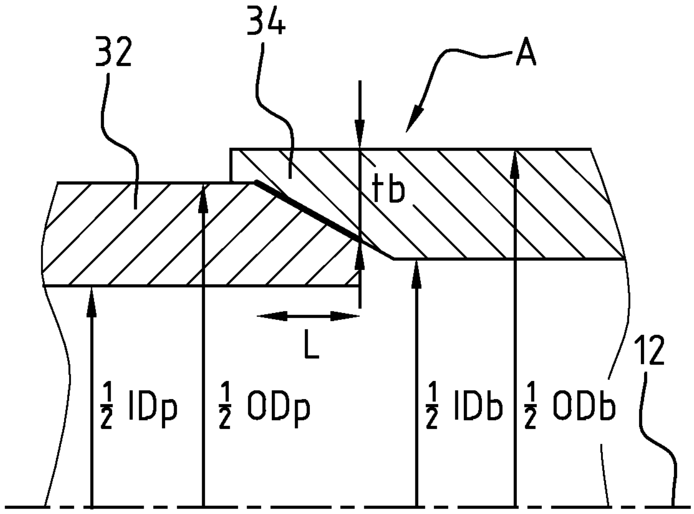


FIG. 2

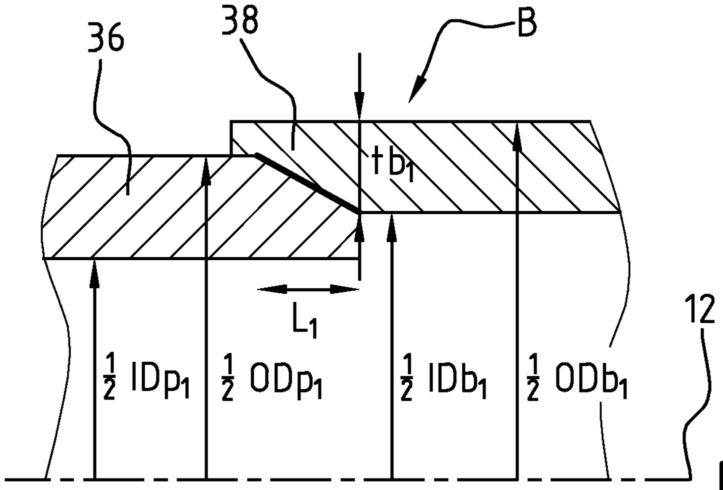


FIG. 3

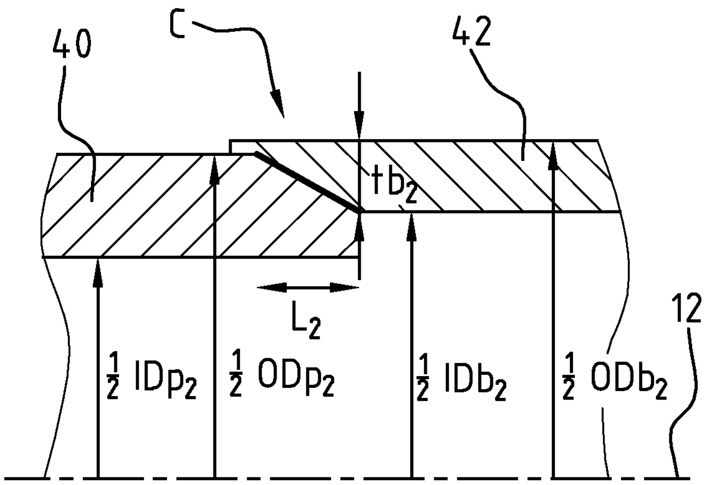


FIG. 4

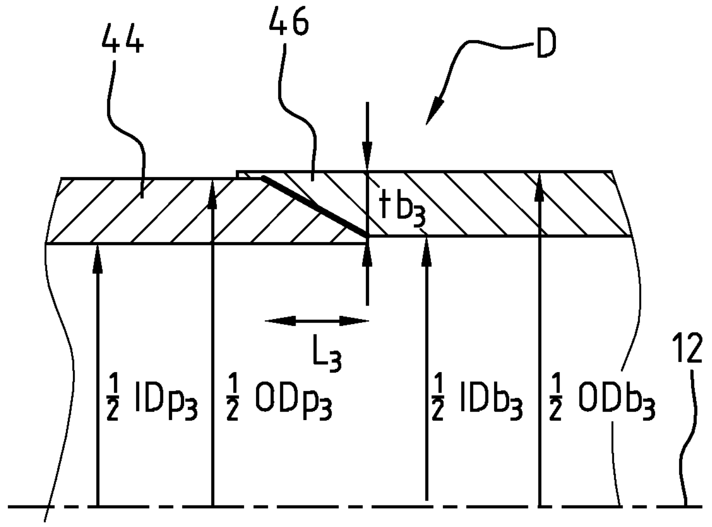


FIG. 5

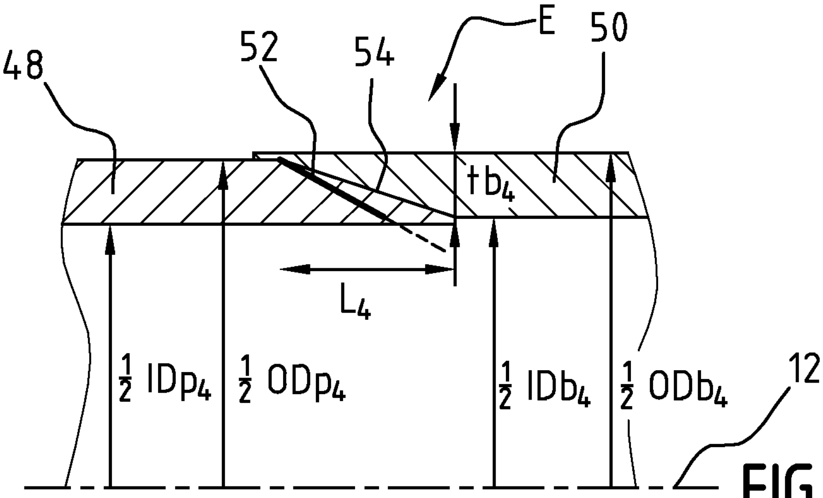


FIG. 6

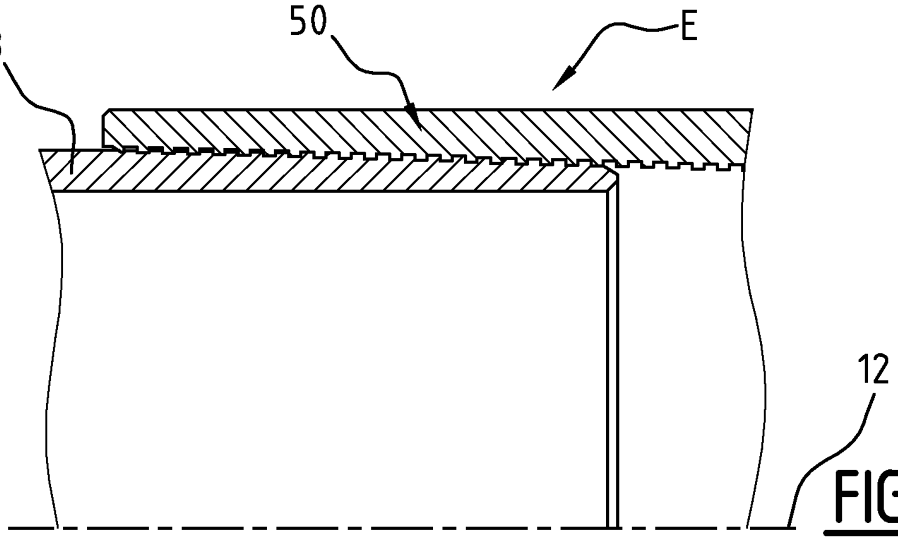


FIG. 7

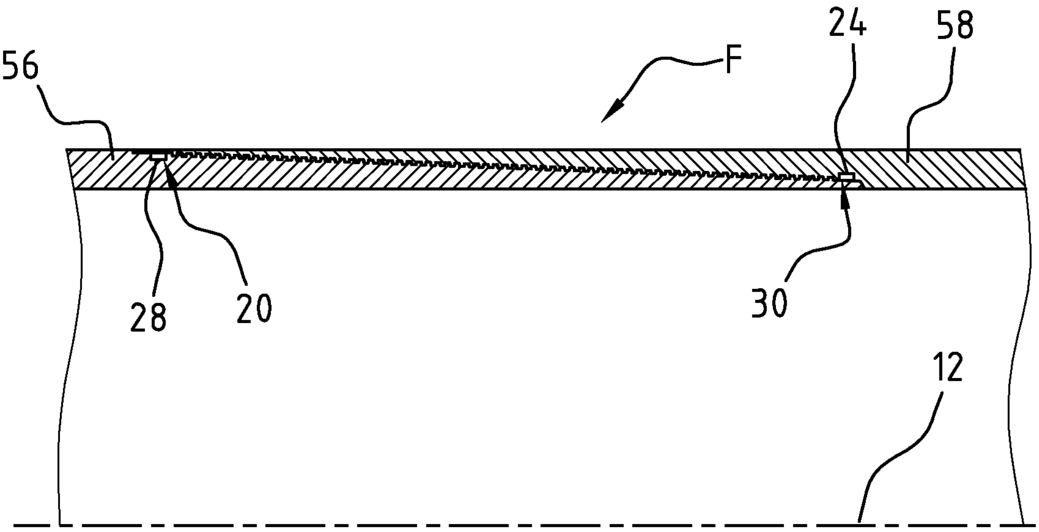


FIG. 8

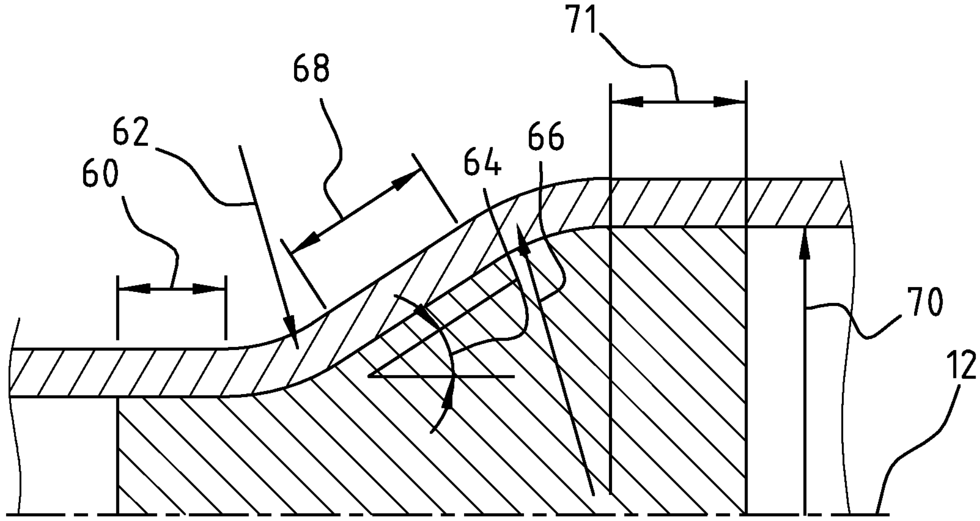


FIG. 9

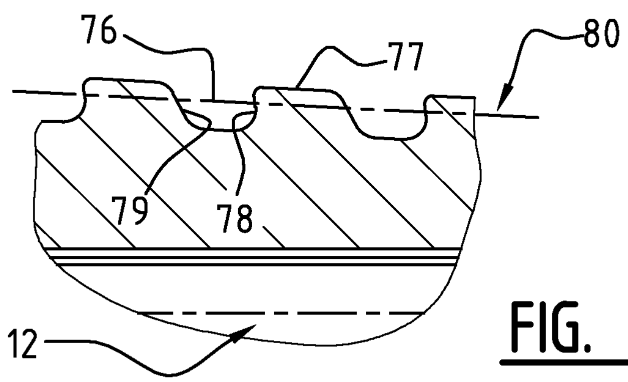
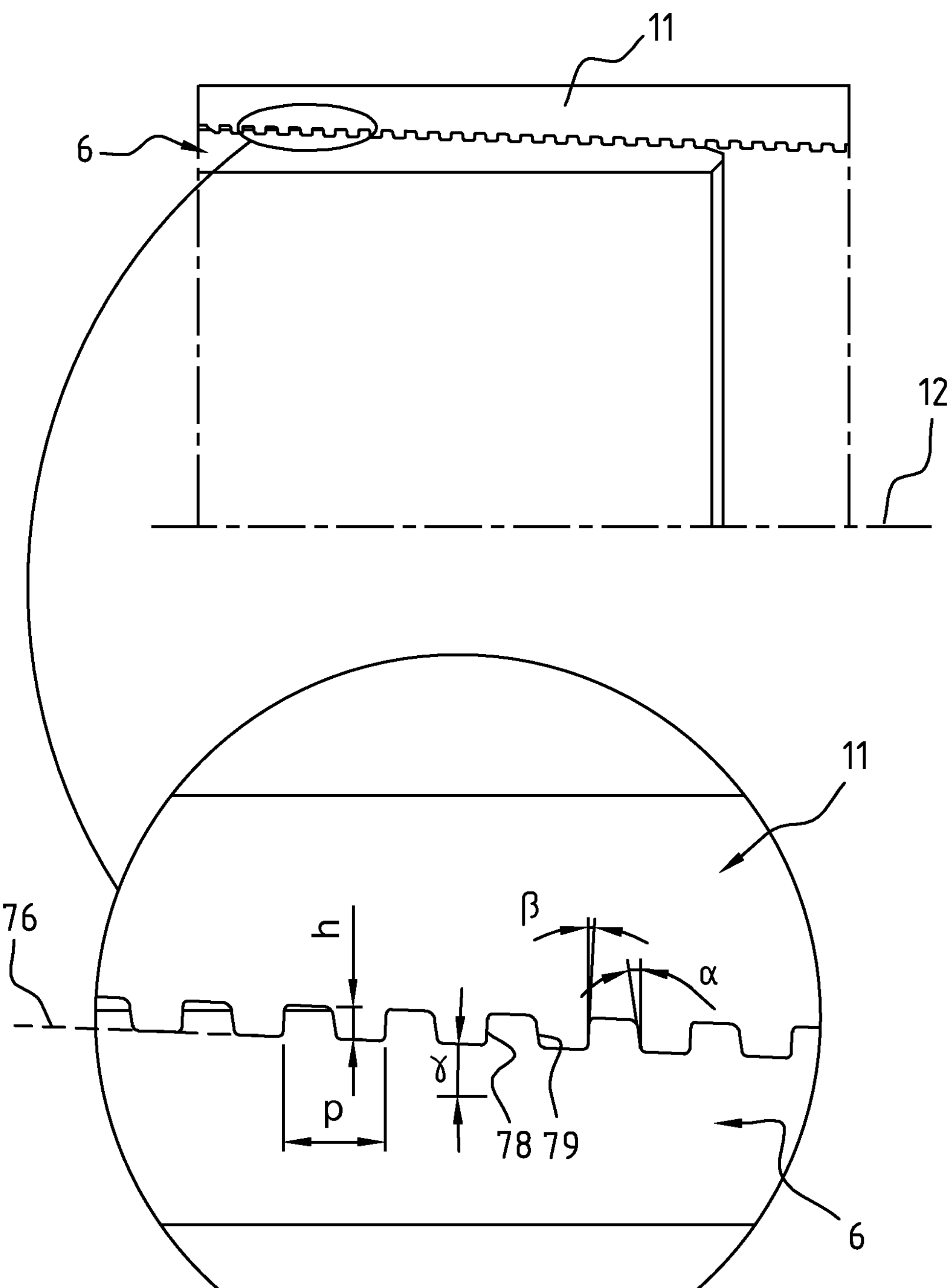
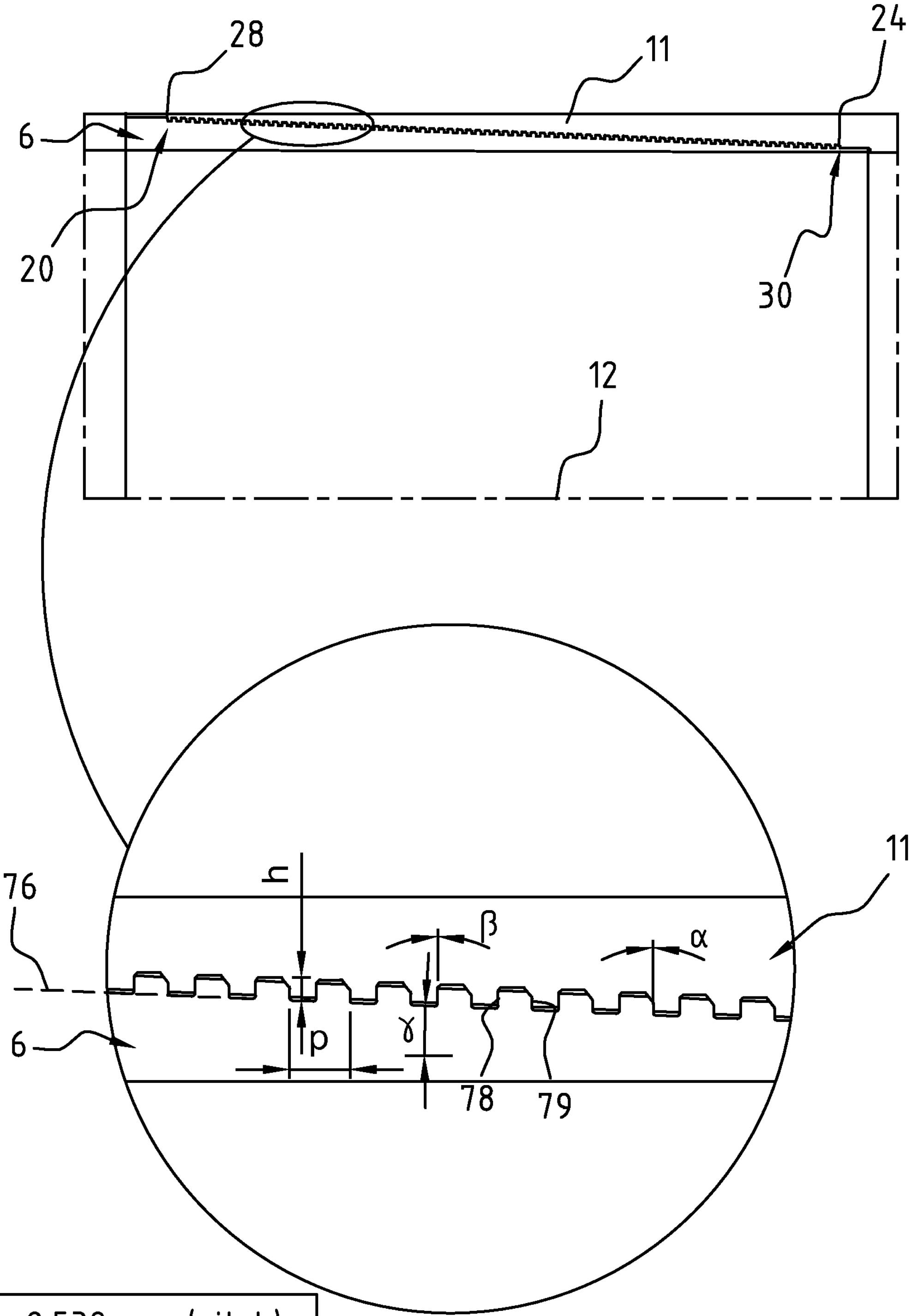


FIG. 10



p=5.08 mm (pitch)
h=1.565 mm (height)
α=10.00°
β=3.00°
γ=1.79°

FIG. 11



p=2.539 mm (pitch)
h=0.845 mm (height)
α=0.00°
β=0.00°
γ=2.29°

FIG. 12

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EUROPEAN SEARCH REPORT

Application Number
EP 12 17 2226

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2004/005665 A2 (WEATHERFORD LAMB [US]; SIMPSON NEIL ANDREW ABERCROMBI [GB]; HARRAL SIM) 15 January 2004 (2004-01-15) * page 10, line 13 - line 18; figures 3,6 *	1-15	INV. E21B17/042
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E21B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	25 September 2012	Strømmen, Henrik

CATEGORY OF CITED DOCUMENTS

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25-09-2012

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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