

Method and arrangement for changing the shape of a sheet-like workpiece

Description

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The present invention relates to a method for changing the shape of a sheet-like workpiece, which has a mould recess formed by reducing the thickness of the material, comprising arranging the workpiece on at least two spaced-apart supporting elements of a machine bed, forming the workpiece into a final shape by step-by-step free bending, in that the steps of

10 bending a part of the workpiece by lowering an upper die between the supporting elements from a waiting position into a forming position, raising the upper die into the waiting position and moving the position of the workpiece relative to the machine bed in at least one infeed direction are performed repetitively.

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In addition, the invention relates to an arrangement for changing the shape of a sheet-like workpiece, which has a mould recess formed by reducing the thickness of the material, comprising at least two spaced-apart supporting elements designed for arranging the workpiece on a machine bed, a forming device designed for forming the workpiece into a final shape by step-by-step, repetitive free bending with an upper die, which is designed to

20 be controllably lowerable from a waiting position into a forming position for bending a part of the workpiece, as well as with positioning means which are designed for moving the position of the workpiece relative to the machine bed in at least one infeed direction.

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Such methods and arrangements are used in particular in the processing of large sheets which serve as the outer skin of aircraft. The sheets have to be shaped according to the outer contour of the fuselage and a workpiece frequently has to be produced with a plurality of different radii. The sheets are often formed into the desired final shape by means of roll forming, i.e. formed by passing between various rolls.

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The formed sheets are then regularly machined to introduce rivet holes, pockets and cut-outs into the already formed workpiece.

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Document DE 10 2011 114 927 A1 discloses a method for circular bending of large sheets to a target radius. Circular bending is performed using a bender by edging several times with a round punch.

The disadvantage is that only full-surface workpieces can be processed using the known methods and arrangements. Machined workpieces, which, for example, already have pockets, rivet holes or cut-outs for windows, cannot be processed satisfactorily with the known methods and arrangements, since such mould recesses in the workpiece lead to uncontrollable deformations of the workpiece in the region of these mould recesses when using the known forming methods.

As a result of this, it is necessary to shape the workpieces first in a bending process and to then machine them afterwards to produce the desired mould recess. As the geometry of the workpiece obtained after the bending process extends spatially, the use of 5-axis portal milling machines is unavoidable for subsequent machining and this is associated with large space requirements and high acquisition and maintenance costs.

It is therefore the object of the present invention to propose a method by means of which sheet-like workpieces that have already been machined can be formed cost-effectively, with high precision and very high repeat accuracy by means of step-by-step free bending. The object is further to propose a corresponding method.

The object is achieved by a method with the features referred to hereinbefore in that, before the workpiece is formed into the final shape, a filling element, which is adapted to the mould recess and designed to make up the material thickness, is produced and is arranged in the region of the mould recess. The method according to the invention offers many advantages over the method known in the prior art. Thus, by means of the invention, a method is created which for the first time allows the bending of workpieces that have already been machined. The workpieces can then be machined before the bending process due to their sheet-like geometry. For this purpose, it is sufficient to use a three-axis metal-cutting machine which in particular also considerably reduces the effort required to clamp the workpiece compared to complex machining using a 5-axis portal milling machine on an already bent workpiece. In this way, the workpieces can be machined significantly more cost-effectively. In addition, using the filling element ensures a high-precision bending operation, particularly in the region of the mould recesses, i.e. in the region of milled-in pockets, rivet holes, window openings or the like and thus achieves extremely good repeat accuracy of the entire bending process.

A preferred development of the invention is characterised in that the filling element is produced at least substantially as a negative form of the mould recess. In other words, the filling element is designed in such a manner that it fits into the mould recess in a positive-locking or substantially positive-locking manner. The filling element thus forms a re-usable intermediate layer which is arranged between the upper die and the workpiece. The filling

element ensures uniform introduction into the workpiece of the forces acting during the bending process and compensates the forming behaviour during the bending process which differs according to the material thickness. Thus the entire workpiece is bent precisely and with high precision and repeat accuracy despite the existing mould recess.

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According to a further preferred embodiment of the invention, in regions of the mould recess with reduced material thickness, the filling element has a minimum thickness in each case which corresponds at least to the amount of reduction in the material thickness of the workpiece in this region. Consequently, the filling element is designed as a compensating element which accurately makes up for the material removed due to the machining process previously performed on the workpiece, such that there is always substantially flat contact between the upper die and the workpiece or the filling element arranged thereon during the forming process. According to a further expedient embodiment of the invention, the filling element is produced in such a manner that, when arranged in the mould recess, it finishes flush with the upper side of the workpiece, forming an at least substantially smooth pressure surface.

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According to a further preferred embodiment, the filling element is produced so as to protrude with respect to the pressure surface in predetermined raised regions. As a result, higher bending forces act locally on the workpiece in the corresponding raised regions during the forming process. In this way, the rebound behaviour of the material, which depends in each case on the local material thickness of the workpiece, is compensated and the bending process is carried out with extremely high precision even in regions where the material thickness of the workpiece differs. In other words, the raised regions of the filling element are designed and configured to compensate the rebound behaviour.

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Alternatively or in addition, the raised regions are formed by a pressure-resistant foil which is arranged on the pressure surface of the filling element. Thus, it is possible to achieve compensation of undesirable rebound behaviour of workpiece regions in a particularly simple and cost-effective way. The foil is advantageously glued on for this purpose and in this way is also secured against undesirable slipping.

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A preferred development of the invention is characterised in that the filling element is made of acrylonitrile butadiene styrene (ABS). ABS is machinable, comparatively inexpensive and has the required physical properties for the forming process. On the one hand, ABS has the required flexibility to return to its original shape after the bending process. On the other hand, ABS has the necessary hardness to transfer the forces generated during the forming process

from the upper die to the workpiece to be formed without deforming notably itself. The filling element is preferably produced by machining. In this way, the filling element can be produced cost-effectively and with high precision.

- 5 An expedient embodiment of the invention is characterised in that a resilient supporting surface element is arranged between the supporting elements of the machine bed and the workpiece. The resilient supporting surface element forms a resilient machine bed. During the forming process, the supporting surface element is elastically co-deformed, thus providing full-surface support for the workpiece. Advantageously, workpieces with a low material thickness can thus be formed on the one hand and on the other hand it is thus also possible to form the end regions of the workpieces with high precision, since the end regions are also always supported during forming.

- 15 The object is also achieved by the arrangement referred to hereinbefore which is characterised in that it further comprises a filling element, adapted to the mould recess and designed to make up the material thickness, which is designed to be arranged in the region of the mould recess before the workpiece is formed into the final shape. To avoid repetition of the associated advantages, reference is made to the remarks above regarding the method according to the invention. The advantages described above also apply by analogy to the arrangement according to the invention as well as to the further advantageous embodiments of the arrangement according to the invention referred to below.

- 25 A further expedient embodiment of the invention is characterised in that the filling element is designed at least substantially as a negative form of the mould recess.

- 30 According to a further preferred embodiment, in regions of the mould recess with reduced material thickness, the filling element has a minimum thickness in each case which corresponds at least to the amount of reduction in the material thickness of the workpiece in this region.

- 35 A further expedient embodiment of the invention is characterised in that the filling element is designed in such a manner that, when arranged in the mould recess, it finishes flush with the upper side of the workpiece, forming an at least substantially smooth pressure surface.

- A preferred development of the invention is characterised in that the filling element is designed to protrude with respect to the pressure surface in predetermined raised regions.

A further expedient embodiment of the invention is characterised in that a pressure-resistant foil is arranged on the pressure surface for producing the raised regions.

- 5 According to a further preferred embodiment, the foil is joined to the pressure surface by means of an adhesive bond.

A further expedient embodiment of the invention is characterised in that the filling element is made of acrylonitrile butadiene styrene (ABS).

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A further expedient embodiment of the invention is characterised in that a resilient supporting surface element is arranged between the supporting elements of the machine bed and the workpiece.

- 15 Further preferred and/or expedient features and embodiments of the invention emerge from the dependent claims and the description. Especially preferred embodiments are explained in greater detail with reference to the attached drawing. The drawing shows:

20 Fig. 1 the schematic view of the arrangement according to the invention according to a first embodiment,

 Fig. 2 a schematic view of the forming process using the arrangement according to the invention,

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 Fig. 3 a further advantageous embodiment of the arrangement according to the invention with a supporting surface element.

- 30 The method according to the invention and the arrangement according to the invention are described in greater detail below based on preferred embodiments. Due to the analogy between method and arrangement, the remarks made in each case regarding the method apply equally to the arrangement according to the invention and vice versa.

- 35 Figure 1 shows a sheet-like workpiece 10 with a mould recess formed by reducing the thickness of the material. For example, the workpiece is a sheet or large sheet for use as the outer skin of an aircraft, in particular made of aluminium alloys containing copper and/or

magnesium with high tensile strength ranging from 400 to 450 N/mm². Such sheets, for example, have dimensions of 800 x 800 mm up to 6000 x 6000 mm. The maximum material thickness of the workpiece 10 varies between 0.5 and 16 mm depending on the application. The method according to the invention and the device according to the invention are suitable for forming workpieces 10 made of plastic or metal, such as sheet aluminium and sheet steel.

The workpiece 10 has a mould recess which is formed by reducing the thickness of the material. As can be gathered from the schematic view in Figure 1, the workpiece 10 has regions 11 of reduced material thickness. These regions 11 form the mould recess. When using the workpieces 10 in the aircraft industry as the outer skin of the aircraft, also referred to as "skins", these regions 11 are introduced into the workpiece 10, for example, by rivet holes, pockets for weight saving, cut-outs for windows or the like. Processing of the workpiece for introducing the mould recess is carried out by machining, for example, on the sheet-like, i.e. flat, workpiece 10 by means of three-axis cutting machines.

To change the shape, for example to adapt the workpiece 10 to the desired aircraft contour, the workpiece is preferably arranged on at least two spaced-apart supporting elements 12 of a machine bed 13. The forming process into the final shape takes place by means of step-by-step free bending. For this purpose, a part of the workpiece 10 is brought from a waiting position, not shown in the drawing, into a forming position 15 by lowering an upper die 14 between the supporting elements 12.

The upper die 14 is then raised, i.e. moved again in z direction 16 into the waiting position. Now the position of the workpiece 10 relative to the machine bed is moved in at least one infeed direction 17. Figure 2 shows the workpiece 10 schematically after one or a plurality of forming processes. The previously described steps are carried out repetitively until the desired final shape is achieved by multiple forming.

More preferably, the positioning means, not shown in the drawing, are designed and configured to move the workpiece 10 not only in the infeed direction 17 shown but additionally in a further direction perpendicular to the infeed direction 17. The workpiece can thus be positioned and moved largely at will in the XY plane. In addition, it is possible to incline the upper die 14 with respect to the Z direction 17. In this way, the workpieces can be twisted to a certain extent during forming.

The local bending radius desired for each forming process is predetermined by specifying the immersion depth of the upper die 14, which is determined by the lowering path. The workpiece 10 is formed into the desired final shape by repetitively carrying out this forming process. Different radii can be introduced into the workpiece 10 by specifying individual immersion depths for each bending operation.

Before the workpiece 10 is formed into the final shape, a filling element 18 adapted to the mould recess and designed to make up the material thickness is produced and is arranged in the region of the mould recess. As shown in Figures 1 and 2, the filling element 18 is arranged on the workpiece 10 to be formed and thus fills in particular the regions 11 of reduced material thickness of the mould recess.

This makes it possible for the first time to subsequently form already machined workpieces 10 by free bending with the said mould recesses without obtaining forming results in these regions, which run contrary to the close tolerances specified, due to regions of reduced material thickness already introduced in the workpiece 10.

Advantageously, the upper die 14 has a sword end 22 coming into contact with the workpiece 10 or the filling element 18. This is preferably made of plastic and has a large radius, preferably greater than 50 mm, on the one hand to bend the workpiece 10 gently and on the other hand to ensure the smoothest possible transitions of the bending radii.

The filling element 18 is preferably produced as a negative form or at least substantially as a negative form of the mould recess. In other words, the filling element 18 has a shape which corresponds to the shape of the regions 11 of reduced material thickness, such that the filling element 18 arranged on the workpiece 10 preferably fills the whole surface of the mould recess and completely compensates the removed material of the workpiece 10 in the region of the mould recess. The filling element 18 with the workpiece 10 thus forms a flat or smooth pressure surface 19 on the upper die side. It is also possible to design the surface filling element 18 such that it only partially covers selected regions of the workpiece 10.

More preferably, in regions 11 of the mould recess with reduced material thickness, the filling element 18 has a minimum thickness in each case which corresponds at least to the amount of reduction in the material thickness of the workpiece 10 in this region. The workpiece 10 with the filling element 18 thus forms the previously described flat pressure surface 19, such that a flat contact between upper die 14 and the workpiece 10 or the filling element 18 is basically guaranteed during the forming process.

The filling element 18 is therefore produced in such a manner that, when arranged in the mould recess, it finishes flush with the upper side 20 of the workpiece 10, forming an at least substantially smooth pressure surface 19.

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According to a preferred development of the invention, not shown in the drawing, it is provided that the filling element is produced so as to protrude with respect to the pressure surface 19 in predetermined raised regions. The workpiece 10 has a different rebound behaviour depending in each case on the local material thickness. Depending on the local material thickness in each case and on the selected bending radius, the material of the workpiece springs back to a varying degree after the forming process.

According to the invention, this rebound behaviour is determined by simulation before the forming process and the rebound behaviour of the whole workpiece 10 to be formed is predicted based on this simulation. Based on this prediction, the raised regions in which the filling element is to be made correspondingly wider are then determined such that the filling element has the said raised regions. Thus in these raised regions, an increased immersion depth is achieved with respect to the remaining regions of the filling element, and in this way the force exerted on the workpiece in the raised regions is increased with respect to the remaining regions during the bending process. As a result, the workpiece 10 is bent more strongly locally in the areas of the raised regions to such an extent that the rebound behaviour of the material is compensated and the workpiece 10 is accurately formed into the desired final shape in all regions.

For example, a process simulation, using a finite element method (FEM) analysis program, is used to determine the raised regions. The bending process can be simulated by modelling the geometry of the upper die 14 and the machine bed 13 as well as of the material properties of the workpiece 10 and the filling element 18, and thus the overall geometry of the filling element 18 can be determined such that the said accurate forming results are achieved.

As explained previously, based on the determined geometry of the filling element 18, the filling element 18 is preferably milled from the solid. Alternatively or in addition, it is possible to arrange pressure-resistant foil on the pressure surface 19 of the filling element for producing the raised regions and thus to adjust the material thickness of the filling element 18 accordingly in the relevant raised regions. More preferably, the foil is glued onto the pressure surface 19 of the filling element 18 and thus secured against undesirable slipping.

The filling element 18 is preferably made of acrylonitrile butadiene styrene (ABS). This material has a modulus of elasticity of 2400 MPa and thus has the required flexibility, on the one hand, to co-deform elastically during the forming process and, on the other hand, to
5 return to its original shape again after the end of the forming process. In this way, the filling element 18 can be used for a plurality of forming processes. The ABS plastic preferably has a hardness of 90 Shore and is suitable for machining.

Alternatively, the filling element 18 can be made of other plastics, fibre composites, cast resin
10 or spring steel. In addition to machining, casting or laminating processes are also used to produce the filling element 18, depending on the material used.

Figure 3 shows a further advantageous embodiment of the arrangement according to the invention, based on which the method according to the invention will also be explained
15 below. A resilient supporting surface element 21 is arranged between the supporting elements 12 of the machine bed 13 and the workpiece 10. The workpiece 10 is thus supported on the at least two supporting elements 12 via the resilient supporting surface element 21. Consequently, the supporting surface element 21 is designed as a resilient machine bed and is elastically co-deformed during the forming process of the workpiece 10,
20 but automatically returns to its original shape after the bending process is complete. The supporting surface element 21 provides full-surface support for the workpiece 10.

Claims

1. Method for changing the shape of a sheet-like workpiece (10), which has a mould
5 recess formed by reducing the thickness of the material, comprising
- arranging the workpiece (10) on at least two spaced-apart supporting elements (12) of
a machine bed (13),
- 10 forming the workpiece (10) into a final shape by step-by-step free bending, in that the
steps of
- bending a part of the workpiece (10) by lowering an upper die (14) between
the supporting elements from a waiting position into a forming position (15),
 - 15 - raising the upper die (14) into the waiting position and
 - moving the position of the workpiece (10) relative to the machine bed (13) in
at least one infeed direction
- 20 are performed repetitively, **characterised in that**
- before the workpiece (10) is formed into the final shape, a filling element (18), which
is adapted to the mould recess and designed to make up the material thickness, is
25 produced and is arranged in the region of the mould recess.
2. Method according to claim 1, characterised in that the filling element (18) is produced
at least substantially as a negative form of the mould recess.
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3. Method according to one of claims 1 or 2, characterised in that, in regions (11) of the
mould recess with reduced material thickness, the filling element (18) has a minimum
thickness in each case which corresponds at least to the amount of reduction in the
35 material thickness of the workpiece (10) in this region.

4. Method according to any one of claims 1 to 3, characterised in that the filling element (18) is produced in such a manner that, when arranged in the mould recess, it finishes flush with the upper side (20) of the workpiece (10), forming an at least substantially smooth pressure surface (19).
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5. Method according to claim 4, characterised in that the filling element (18) is produced so as to protrude with respect to the pressure surface (19) in predetermined raised regions.
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6. Method according to claim 5, characterised in that a pressure-resistant foil is arranged on the pressure surface (19) of the filling element (18) for producing the raised regions.
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7. Method according to claim 6, characterised in that the foil is glued on.
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8. Method according to any one of claims 1 to 7, characterised in that the filling element (18) is made of acrylonitrile butadiene styrene (ABS).
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9. Method according to any one of claims 1 to 8, characterised in that the filling element (18) is produced by machining.
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10. Method according to any one of claims 1 to 9, characterised in that a resilient supporting surface element (21) is arranged between the supporting elements (12) of the machine bed (13) and the workpiece (10).
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11. Arrangement for changing the shape of a sheet-like workpiece (10), which has a mould recess formed by reducing the thickness of the material, comprising
- at least two spaced-apart supporting elements (12) designed for arranging the workpiece (10) on the machine bed (13),

a forming device designed for forming the workpiece (10) into a final shape by step-by-step, repetitive free bending with an upper die (14), which is designed to be controllably lowerable from a waiting position into a forming position (15) for bending a part of the workpiece (10) as well as

with positioning means which are designed for moving the position of the workpiece (10) relative to the machine bed (13) in at least one infeed direction,

characterised in that

the arrangement further comprises a filling element (18) adapted to the mould recess and designed to make up the material thickness which is designed to be arranged in the region of the mould recess before the workpiece (10) is formed into the final shape.

12. Arrangement according to claim 11, characterised in that the filling element (18) is designed at least substantially as a negative form of the mould recess.

13. Arrangement according to one of claims 11 or 12, characterised in that, in regions (11) of the mould recess with reduced material thickness, the filling element (18) has a minimum thickness in each case which corresponds at least to the amount of reduction in the material thickness of the workpiece (10) in this region.

14. Arrangement according to any one of claims 11 to 13, characterised in that the filling element (18) is designed in such a manner that, when arranged in the mould recess, it finishes flush with the upper side (20) of the workpiece (10) forming an at least substantially smooth pressure surface (19).

15. Arrangement according to claim 14, characterised in that the filling element (18) is designed so as to protrude with respect to the pressure surface (19) in predetermined raised regions.

16. Arrangement according to claim 15, characterised in that a pressure-resistant foil is arranged on the pressure surface (19) for producing the raised regions.
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17. Arrangement according to claim 16, characterised in that the foil is joined to the pressure surface (19) by means of an adhesive bond.
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18. Arrangement according to any one of claims 11 to 17, characterised in that the filling element (18) is made of acrylonitrile butadiene styrene (ABS).
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19. Arrangement according to any one of claims 11 to 18, characterised in that a resilient supporting surface element (21) is arranged between the supporting elements (12) of the machine bed (13) and the workpiece (10).