[0004] The finishing tool may be operated by a human, or may be automatically controlled. For example, the finishing tool may follow the surface of the component (or vice-versa), and remove a specific amount of material from the surface of the component (the amount may vary based on the current position of the finishing tool on the surface). However, the precision of the finishing operation may not be sufficient, and a significant amount of rework may be needed, in order to comply with specifications of the finished component.

[0005] Furthermore, the finishing tool may be used to finish different types of components, each having its own requirements.

[0006] At the moment, a finishing recipe for automatically controlled finishing tool is obtained by successive trial and errors performed by one or several operators, until a 'good enough' finishing recipe is obtained. The trial and errors require operator and equipment time, and the finishing recipe is appropriate as long as the components to be finished remain within a certain range of variations.

[0007] Therefore, there is a need for a computer-implemented method for automatically determining a finishing recipe of a manufactured component, which overcomes the aforementioned limitations.

SUMMARY

[0008] According to a first aspect, the present disclosure provides a computer-implemented method for automatically determining a finishing recipe of a manufactured component. The method comprises receiving, at a computer, a non-finished 3D model consisting in a 3D representation of the manufactured component at a non-finished stage, and a finished 3D model consisting in a 3D representation of the manufactured component at a finished stage. The method further comprises processing, at the computer, the non-finished 3D model and the finished 3D model to determine an initial finishing recipe of one or more finishing tool(s). The finishing tool performs a finishing

operation according to the calculated initial finishing recipe on the manufactured component at the non-finished stage, to obtain the manufactured component at the finished stage. The method further compares the manufactured component at the finished stage with the 3D representation of the manufactured component at the finished stage, to identify quantitative differences. The method further applies a convergence algorithm to the initial finishing recipe using the quantitative differences to obtain a converged finishing recipe.

[0009] According to a second aspect, the present disclosure provides a computer program product deliverable via computer-readable media such as storage media and communication links. The computer program product comprises instructions for automatically determining a finishing recipe of a manufactured component. The instructions, when executed by a processor, effect a reception of a non-finished 3D model consisting in a 3D representation of the manufactured component at a non-finished stage, and of the manufactured component at a finished stage. The instructions further effect a processing of the non-finished 3D model and the finished 3D model to calculate an initial finishing recipe of a finishing tool. The finishing tool performs a finishing operation according to the calculated initial finishing recipe on the manufactured component at the non-finished stage, to obtain the manufactured component at the finished stage. The computer program product further compares the manufactured component at the finished stage with the 3D representation of the manufactured component at the finished stage, to identify quantitative differences. The computer program product further applies a convergence algorithm to the initial finishing recipe using the quantitative differences to obtain a converged finishing recipe.

[0010] According to a third aspect, the present disclosure provides a system for automatically determining and applying a finishing recipe of a manufactured component. The system comprises a computer implementing the aforementioned computer-implemented method for calculating a finishing

iteratively using the converged finishing recipe for finishing subsequent manufactured components, comparing the manufactured component with the 3D representation of the manufactured component at the finished stage to identify quantitative differences, and applying the convergence algorithm to the converged finishing recipe with the quantitative differences to optimize the converged finishing recipe. Depending on the level of precision required of the manufactured component and/or of the precision of the finishing tool and/or predetermined tolerated quantitative differences, the present method may repeat the inspection and convergence steps after finishing each manufactured component, or after a certain number of finished manufactured components, or a combination of both.

[0033] The non-finished 3D model is a theoretically perfect 3D representation, which accurately complies with specifications of the manufactured component at the non-finished stage. Similarly, the finished 3D model is a theoretically perfect 3D representation, which accurately complies with specifications of the manufactured component at the finished stage. Both 3D models may be generated by a Computer Aided Design (CAD) software executed on the current computer, or on a different computer and transmitted to the current computer. 3D representation can to both a virtual graphical representation or to measurements obtained the system inspection device.

[0034] In a particular aspect, the calculated finishing recipe includes a calculated trajectory of the tool performing the finishing operation. The trajectory defines physical interactions of the finishing tool with the manufactured component, when performing the finishing operation. For instance, the manufactured component is held in a fixed position by a supporting device, and the finishing tool is in movement with respect to the manufactured component to perform the finishing operation. The movement of the finishing tool is controlled by a processing unit, capable of interpreting the calculated trajectory. The processing unit transforms the calculated trajectory in effective movements of the finishing tool for performing the finishing

the blade are represented on Figure 2b.

[0051] Figure 3 illustrates a finishing tool 300 performing the profiling of the blade 310 according to the calculated recipe: for each section of the blade, execute the number of passes determined by the algorithms and follow the trajectory determined by the algorithms for each of the passes.

[0052] Now referring to Figures 4, 5, 6a-6c, and 7a-7c, the profiling of a blade according to a calculated trajectory will be further detailed.

[0053] Figure 4 illustrates a front elevation view of the blade of Figure 2a. For illustration purposes, a profiling operation on the upper edge 410 along the section determined by line AA is further described.

[0054] Figure 5 illustrates a cross-sectional view of the blade of Figure 4 as viewed from line A-A. A non-finished profile 510 and a finished profile 520 are represented. The non-finished profile 510 represents a 2D representation of a specific section of the blade at a non-finished stage. The finished profile 550 represents a 2D representation of a specific section of the blade at a finished stage. The non-finished profile 510 is extracted from a non-finished 3D model (as illustrated in Figure 2a) consisting in a 3D representation of the blade at a non-finished stage. The finished profile 520 is extracted from a finished 3D model (as illustrated in Figure 2a) consisting in a 3D representation of the blade at a finished stage.

[0055] Figures 6a-6c illustrate a first pass of the profiling operation on the specific profile of the blade represented in Figure 5. Referring to Figure 6a, a tangent 610 to the finished profile 520, at a determined point of contact 620 with the finished profile 520, is calculated. The tangent 610 defines a point of contact 630 with the non-finished profile 510, and an angle with a reference vertical line 640. Referring to Figure 6b, a trajectory of a profiling tool 650 for the first pass is illustrated. The trajectory corresponds to the tangent 610, starting at the point of contact 630 with the non-finished profile 510. More particularly, the trajectory could be following a sweep movement on various

WHAT IS CLAIMED IS:

1. A computer-implemented method for automatically determining a finishing recipe of a manufactured component, the method comprising:

receiving at a computer a non-finished 3D model consisting in a 3D representation of the manufactured component at a non-finished stage;

receiving at the computer a finished 3D model consisting in a 3D representation of the manufactured component at a finished stage; and

processing at the computer the non-finished 3D model and the finished 3D model to calculate a finishing recipe of a tool performing a finishing operation according to the calculated finishing recipe on the manufactured component at the non-finished stage to obtain the manufactured component at the finished stage.

2. The computer-implemented method of claim 1, wherein the finishing recipe comprises at least one of a trajectory of the tool performing the finishing operation, and an operational parameter(s) of the tool performing the finishing operation.

3. The computer-implemented method of claim 1, wherein the finishing operation consists in one of profiling, polishing, tri-blending, weld blending, and twist and bow.

4. The computer-implemented method of claim 1, wherein the manufactured component consists in a blade.

5. The computer-implemented method of claim 1, wherein measured characteristics of a manufactured component at the finished stage are compared to corresponding characteristics of a model of the manufactured component at the finished stage, and differences between the measured characteristics and the corresponding

characteristics are used to optimize the calculation of the finishing recipe.

6. The computer-implemented method of claim 5, wherein the measured characteristics of the manufactured component at the finished stage are determined by an automated inspection system.

7. The computer-implemented method of claim 2, wherein the trajectory of the tool performing the finishing operation consists in several passes of the tool, each pass consisting in a sub-trajectory of the tool calculated by the computer.

8. The computer-implemented method of claim 5, wherein the sub-trajectory is a tangent to the finished 3D model at a calculated point of the finished 3D model, the tangent defining an angle with a reference line common to the non-finished and finished 3D models, and the tangent defining a point of contact with the non-finished 3D model.

9. The computer-implemented method of claim 5, wherein an optimization algorithm is used to optimize one of: the number of passes, the sub-trajectory of the passes, and a combination thereof.

10. A computer program product deliverable via computer-readable media such as storage media and communication links, the computer program product comprising instructions for automatically determining a finishing recipe of a manufactured component that when executed by a processor effect:

a reception of a non-finished 3D model consisting in a 3D representation of the manufactured component at a non-finished stage;

a reception of a finished 3D model consisting in a 3D representation of the manufactured component at a finished stage; and

a processing of the non-finished 3D model and the finished 3D model to calculate a finishing recipe of a tool performing a finishing operation according to the calculated finishing recipe on the

manufactured component at the non-finished stage to obtain the manufactured component at the finished stage.

11. The computer program product of claim 10, wherein the finishing recipe comprises at least one of a trajectory of the tool performing the finishing operation, and operational parameter(s) of the tool performing the finishing operation.

12. The computer program product of claim 10, wherein the finishing operation consists in one of profiling, polishing, tri-blending, weld blending, and twist and bow.

13. The computer program product of claim 10, wherein the manufactured component consists in a blade.

14. The computer program product of claim 10, wherein measured characteristics of a manufactured component at the finished stage are compared to corresponding characteristics of a model of the manufactured component at the finished stage, and differences between the measured characteristics and the corresponding characteristics are used to optimize the calculation of the finishing recipe.

15. The computer program product of claim 14, wherein the measured characteristics of the manufactured component at the finished stage are determined by an automated inspection system.

16. The computer program product of claim 11, wherein the trajectory of the tool against the part or the part against the tool performing the finishing operation consists in several passes of the tool, each pass consisting in a sub-trajectory of the tool calculated by the computer program product.

17. The computer program product of claim 16, wherein the sub-trajectory is a tangent to the finished 3D model at a calculated point of the finished 3D model, the tangent defining an angle with a reference line common to the non-finished and finished 3D models, and the tangent defining a

point of contact with the non-finished 3D model.

18. The computer program product of claim 16, wherein an optimization algorithm is used to optimize one of: the number of passes, the sub-trajectory of the passes, and a combination thereof.

19. A system for automatically determining and applying a finishing recipe of a manufactured component, the system comprising:

a computer implementing the computer-implemented method of claim 1 for calculating a finishing recipe; and

a finishing tool performing a finishing operation on the manufactured component according to the calculated finishing recipe.

[0004] The finishing tool may be operated by a human, or may be automatically controlled. For example, the finishing tool may follow the surface of the component (or vice-versa), and remove a specific amount of material from the surface of the component (the amount may vary based on the current position of the finishing tool on the surface). However, the precision of the finishing operation may not be sufficient, and a significant amount of rework may be needed, in order to comply with specifications of the finished component.

[0005] Furthermore, the finishing tool may be used to finish different types of components, each having its own requirements.

[0006] At the moment, a finishing recipe for automatically controlled finishing tool is obtained by successive trial and errors performed by one or several operators, until a 'good enough' finishing recipe is obtained. The trial and errors require operator and equipment time, and the finishing recipe is appropriate as long as the components to be finished remain within a certain range of variations.

[0006a] US 2012/077417 A1 discloses a method and a device for machining the leading edge of a turbine engine blade by a machining center for which parameters are set. The method includes acquiring a 3D profile of the leading edge of the blade, calculating at least one characteristic of the leading edge from the 3D profile, comparing the value of the calculated characteristic with a known theoretical value of the characteristic to obtain an elementary difference for the characteristic, calculating at least one undulation of the leading edge between at least two consecutive elementary sections from the 3D profile, optimizing the elementary differences obtained as a function of the undulation, setting the parameters of the machining center as a function of the optimized elementary differences for the elementary sections to define machining passes over the leading edge, and machining the leading edge of the blade with the machining center with parameters set.

[0006b] US 2013/035781 A1 discloses a method for controlling the

machining of a component. The method includes measuring predetermined dimensions of a component, comparing the measured dimensions against design data defining a required shape for the component, using the results of the comparison to define material removal that is needed to bring the component to the required shape, using the defined material removal and a known position of a robotic manipulator at a machining station to determine movements of a material removal tool that will produce the required shape for the component, and performing a machining operation on the component at the machining station using the determined movements while maintaining a grip on the component by the robotic manipulator.

[0006c] US 2009/319077 A1 discloses a method for performing a machining operation on a part. The method uses closed-loop control, based on feedback of information measured from the part, from tools and machines, and from an environment, to modify controlling parameters for the machining operation.

[0006d] Although the three aforementioned references describe various methods for controlling the manufacturing of a component by an automated guided tool based on a model of the finished component and data acquired from the manufactured component in its current state of manufacturing, they fail to disclose the calculation of an optimized trajectory of the manufacturing tool to make the finishing of a component faster while preserving accuracy.

[0007] Therefore, there is a need for a computer-implemented method for automatically determining a finishing recipe of a manufactured component, which overcomes the aforementioned limitations.

SUMMARY

[0007a] The invention is defined in the independent claims. Some optional features of the invention are defined in the dependent claims.

[0008] According to a first aspect, the present disclosure provides a computer-implemented method for automatically determining a finishing recipe of a manufactured component. The method comprises receiving, at a computer, a non-finished 3D model consisting in a 3D representation of the manufactured component at a non-finished stage, and a finished 3D model consisting in a 3D representation of the manufactured component at a finished stage. The method further comprises processing, at the computer, the non-finished 3D model and the finished 3D model to determine an initial finishing recipe of one or more finishing tool(s). The finishing tool performs a finishing operation according to the calculated initial finishing recipe on the manufactured component at the non-finished stage, to obtain the manufactured component at the finished stage. The method further compares the manufactured component at the finished stage with the 3D representation of the manufactured component at the finished stage, to identify quantitative differences. The method further applies a convergence algorithm to the initial finishing recipe using the quantitative differences to obtain a converged finishing recipe.

[0009] According to a second aspect, the present disclosure provides a computer program product deliverable via computer-readable media such as storage media and communication links. The computer program product comprises instructions for automatically determining a finishing recipe of a manufactured component. The instructions, when executed by a processor, effect a reception of a non-finished 3D model consisting in a 3D representation of the manufactured component at a non-finished stage, and a reception of a finished 3D model consisting in a 3D representation of the manufactured component at a finished stage. The instructions further effect a processing of the non-finished 3D model and the finished 3D model to calculate an initial finishing recipe of a finishing tool. The finishing tool performs a finishing operation according to the calculated initial finishing recipe on the manufactured component at the non-finished stage, to obtain the manufactured component at the finished stage. The computer program product

further compares the manufactured component at the finished stage with the 3D representation of the manufactured component at the finished stage, to identify quantitative differences. The computer program product further applies a convergence algorithm to the initial finishing recipe using the quantitative differences to obtain a converged finishing recipe.

[0010] According to a third aspect, the present disclosure provides a system for automatically determining and applying a finishing recipe of a manufactured component. The system comprises a computer implementing the aforementioned computer-implemented method for calculating a finishing

iteratively using the converged finishing recipe for finishing subsequent manufactured components, comparing the manufactured component with the 3D representation of the manufactured component at the finished stage to identify quantitative differences, and applying the convergence algorithm to the converged finishing recipe with the quantitative differences to optimize the converged finishing recipe. Depending on the level of precision required of the manufactured component and/or of the precision of the finishing tool and/or predetermined tolerated quantitative differences, the present method may repeat the inspection and convergence steps after finishing each manufactured component, or after a certain number of finished manufactured components, or a combination of both.

[0033] The non-finished 3D model is a theoretically perfect 3D representation, which accurately complies with specifications of the manufactured component at the non-finished stage. Similarly, the finished 3D model is a theoretically perfect 3D representation, which accurately complies with specifications of the manufactured component at the finished stage. Both 3D models may be generated by a Computer Aided Design (CAD) software executed on the current computer, or on a different computer and transmitted to the current computer. The 3D representation can also be replaced to both a virtual graphical representation or to live measurements obtained by the system inspection device.

[0034] In a particular aspect, the calculated finishing recipe includes a calculated trajectory of the tool performing the finishing operation. The trajectory defines physical interactions of the finishing tool with the manufactured component, when performing the finishing operation. For instance, the manufactured component is held in a fixed position by a supporting device, and the finishing tool is in movement with respect to the manufactured component to perform the finishing operation. The movement of the finishing tool is controlled by a processing unit, capable of interpreting the calculated trajectory. The processing unit transforms the calculated trajectory in effective movements of the finishing tool for performing the finishing

the blade are represented on Figure 2b.

[0051] Figure 3 illustrates a finishing tool 300 performing the profiling of the blade 310 according to the calculated recipe: for each section of the blade, execute the number of passes determined by the algorithms and follow the trajectory determined by the algorithms for each of the passes.

[0052] Now referring to Figures 4, 5, 6a-6c, and 7a-7c, the profiling of a blade according to a calculated trajectory will be further detailed.

[0053] Figure 4 illustrates a front elevation view of the blade of Figure 2a. For illustration purposes, a profiling operation on the upper edge 410 along the section determined by line A-A is further described.

[0054] Figure 5 illustrates a cross-sectional view of the blade of Figure 4 as viewed from line A-A. A non-finished profile 510 and a finished profile 520 are represented. The non-finished profile 510 represents a 2D representation of a specific section of the blade at a non-finished stage. The finished profile 550 represents a 2D representation of a specific section of the blade at a finished stage. The non-finished profile 510 is extracted from a non-finished 3D model (as illustrated in Figure 2a) consisting in a 3D representation of the blade at a non-finished stage. The finished profile 520 is extracted from a finished 3D model (as illustrated in Figure 2a) consisting in a 3D representation of the blade at a finished stage.

[0055] Figures 6a-6c illustrate a first pass of the profiling operation on the specific profile of the blade represented in Figure 5. Referring to Figure 6a, a tangent 610 to the finished profile 520, at a determined point of contact 620 with the finished profile 520, is calculated. The tangent 610 defines a point of contact 630 with the non-finished profile 510, and an angle with a reference vertical line 640. Referring to Figure 6b, a trajectory of a profiling tool 650 for the first pass is illustrated. The trajectory corresponds to the tangent 610, starting at the point of contact 630 with the non-finished profile 510. More particularly, the trajectory could be following a sweep movement on various

WHAT IS CLAIMED IS:

1. A computer-implemented method for automatically determining a finishing recipe of a manufactured component, the method comprising:

receiving at a computer a non-finished 3D model consisting in a 3D representation of the manufactured component at a non-finished stage;

receiving at the computer a finished 3D model consisting in a 3D representation of the manufactured component at a finished stage; and

processing at the computer the non-finished 3D model and the finished 3D model to calculate a finishing recipe of a tool performing a finishing operation according to the calculated finishing recipe on the manufactured component at the non-finished stage to obtain the manufactured component at the finished stage; wherein

the finishing recipe comprises a trajectory, of the tool performing the finishing operation, the trajectory consisting in several passes of the tool, each pass consisting in a sub-trajectory of the tool calculated by the computer, wherein the sub-trajectory is a tangent to the finished 3D model at a calculated point of the finished 3D model, the tangent defining an angle with a reference line common to the non-finished and finished 3D models, and the tangent defining a point of contact with the non-finished 3D model.

2. The computer-implemented method of claim 1, wherein the finishing recipe further comprises an operational parameter(s) of the tool performing the finishing operation.

3. The computer-implemented method of claim 1, wherein the finishing operation consists in one of profiling, polishing, tri-blending, weld blending, and twist and bow.

4. The computer-implemented method of claim 1, wherein measured characteristics of the manufactured component at the finished stage are compared to corresponding characteristics of the model of the manufactured component at the finished stage, and differences between the measured characteristics and the corresponding characteristics are used to optimize the calculation of the finishing recipe.

5. The computer-implemented method of claim 4, wherein the measured characteristics of the manufactured component at the finished stage are determined by an automated inspection system.

6. The computer-implemented method of claim 1, wherein an optimization algorithm is used to optimize one of: the number of passes, the sub-trajectory of the passes, and a combination thereof.

7. A computer program product deliverable via computer-readable media such as storage media and communication links, the computer program product comprising instructions for automatically determining a finishing recipe of a manufactured component that when executed by a processor effect:

a reception of a non-finished 3D model consisting in a 3D representation of the manufactured component at a non-finished stage;

a reception of a finished 3D model consisting in a 3D representation of the manufactured component at a finished stage; and

a processing of the non-finished 3D model and the finished 3D model to calculate a finishing recipe of a tool performing a finishing operation according to the calculated finishing recipe on the manufactured component at the non-finished stage to obtain the manufactured component at the finished stage; wherein

the finishing recipe comprises a trajectory of the tool performing the finishing operation, the trajectory consisting in several passes of the

tool, each pass consisting in a sub-trajectory of the tool calculated by the computer program product, wherein the sub-trajectory is a tangent to the finished 3D model at a calculated point of the finished 3D model, the tangent defining an angle with a reference line common to the non-finished and finished 3D models, and the tangent defining a point of contact with the non-finished 3D model.

8. The computer program product of claim 7, wherein the finishing operation consists in one of profiling, polishing, tri-blending, weld blending, and twist and bow.

9. The computer program product of claim 7, wherein measured characteristics of the manufactured component at the finished stage are compared to corresponding characteristics of the model of the manufactured component at the finished stage, and differences between the measured characteristics and the corresponding characteristics are used to optimize the calculation of the finishing recipe.

10. The computer program product of claim 9, wherein:

the measured characteristics of the manufactured component at the finished stage are determined by an automated inspection system.

11. The computer program product of claim 10, wherein an optimization algorithm is used to optimize one of: the number of passes, the sub-trajectory of the passes, and a combination thereof.

12. A system for automatically determining and applying a finishing recipe of a manufactured component, the system comprising:

a computer implementing the computer-implemented method of any one of claims 1 to 6 for calculating a finishing recipe; and

a finishing tool performing a finishing operation on the manufactured component according to the calculated finishing recipe.