Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2735299 A1 2012/09/25

(21) 2 735 299

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(22) Date de dépôt/Filing Date: 2011/03/25

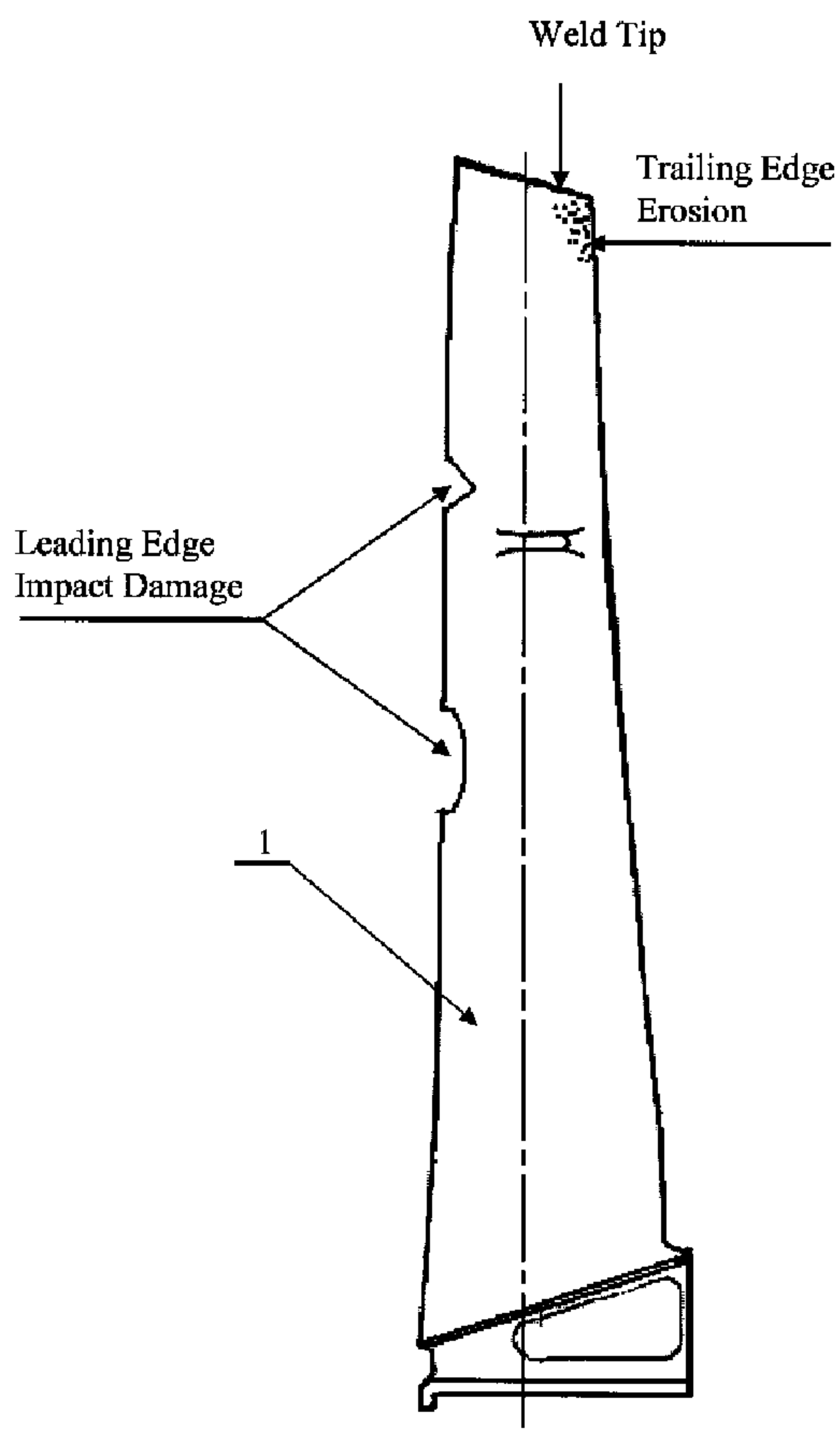
(41) Mise à la disp. pub./Open to Public Insp.: 2012/09/25

(51) Cl.Int./Int.Cl. *B23P 6/00* (2006.01), *F01D 5/14* (2006.01), *F01D 5/28* (2006.01), *F02C 7/30* (2006.01)

(71) Demandeur/Applicant:
LIBURDI ENGINEERING LIMITED, CA

(72) Inventeurs/Inventors:
GONTCHAROV, ALEXANDRE, CA;
LIBURDI, JOSEPH, CA;
TOLLETT, ROBERT, CA;
PISTOR, ROB, CA

(54) Titre : PROFIL AERODYNAMIQUE ET SON PROCEDE DE REPARATION
(54) Title: AIRFOIL AND METHOD OF A REPAIR THE SAME



(57) Abrégé/Abstract:
An airfoil consisting of a stub of a defects free parent material and repair section that comprises a consecutive sequence of ductile alpha or near to alpha titanium layers making from 10 to 50% of a total width of a repair section, and high strength alpha - beta or

(57) Abrégé(suite)/Abstract(continued):
beta titanium layers that are bonded to ductile layers making from 50 to 90% of a width of a repair section with a width of each layer varying from 0.5 to 20 times of an average thickness of a corresponded section of an airfoil, and method of a repair the same by bonding of ductile and high strength layers by fusion welding or cladding followed by heat treatment, machining and non destructive testing of airfoils.

Abstract

An airfoil consisting of a stub of a defects free parent material and repair section that comprises a consecutive sequence of ductile alpha or near to alpha titanium layers making from 10 to 50% of a total width of a repair section, and high strength alpha – beta or beta titanium layers that are bonded to ductile layers making from 50 to 90% of a width of a repair section with a width of each layer varying from 0.5 to 20 times of an average thickness of a corresponded section of an airfoil, and method of a repair the same by bonding of ductile and high strength layers by fusion welding or cladding followed by heat treatment, machining and non destructive testing of airfoils.

AIRFOIL AND METHOD OF A REPAIR THE SAME

Blisks, fan, compressor and turbine blades of aircraft and industrial engines are subjected to severe erosion, corrosion and foreign object damage (FOD). Conditions of blades affect the engine performance and increase fuel consumption. As a result, damaged blades should be replaced within new or repaired ones. Weld repair of blades can be done either by replacing of a damaged section within new patches or direct weld build-up followed by machining or polishing of airfoils to restore the original contour of blades. The patch repair has been used mostly for fan blades restoration. The weld build-up or cladding method is more cost effective for a repair of compressor and turbine blades. Major advantages and weaknesses of these two different types of repair methods are discussed hereafter.

A typical patch repair method of fan blades per the US Patent 5,092,942 by Michael J. Fraser et al comprises steps of removing of a damaged portion of an airfoil by machining or grinding, fusion welding of a patch to a machined area of an airfoil, post weld heat treatment of a blade in protective atmosphere followed by machining and polishing of a patch to a desired shape. In addition to above, a portion of a patch could be hardened by diffusion alloying or plasma spray coating to enhance the erosion resistance of blades.

Karl-Hermann Richter et al improved this method by standardizing the patch size to ease the mass production repair of fan blades as per the US Patent 5,479,704.

William D. Owen et al invented the method that is described in the US Patent 6,339,878 for selecting of a patch line using a stress profile and determination of those regions likely to be damaged during operations followed by a fusion welding of a patch to an airfoil stump and machining.

Further improvement of a patch repair method per the US Patent 4,118,147 by Delmar H. Ellis comprises manufacturing of a patch of composite materials having elongated filaments that are embedded into a matrix that is made either of similar or dissimilar materials aiming to eliminate the stripe mode resonance and increasing fatigue life of blades.

The same approach of creating of a composite structure in a repair area with superior mechanical properties and erosion resistance was further explored by Raymond Delmaire in the US Patent 5,795,412, wherein the blade body was made of alpha-beta titanium alloy while insert was produced of a hardened beta titanium alloy that was welded directly to a stump of an airfoil and additionally hardened by a post weld heat treatment.

In accordance with the US Patent 5,142,778 by John J Smolinski et al, refurbishing of blades comprises a repair of cracks and other defects and replacement of worn or eroded material followed by a laser melting of a thin layer of metal on a surface of a component in those areas requiring reconfiguration to return them to original dimensions.

The major disadvantage of many of prior arts above is a low impact toughness of welds in high strength alpha – beta and beta titanium alloys that are used for patch and inserts repairs that might result in the airfoil failure in case of FOD.

In addition to above, machining of thick patches and inserts to reproduce the original shape of airfoils significantly increased the repair cost.

The further disadvantage of described above prior arts is distortion of airfoils that is resulted by butt welding of dissimilar thickness materials. To restore required shape most blades after patch repair should be subjected to the hot straightening that significantly reduces productivity and further increases the cost of a patch repair.

The laser, micro plasma and automatic gas tungsten arc weld deposition or cladding is much more cost effective for a repair of blades because it can produce the near to net shape weld build up with amount of excessive material of 0.2 – 0.5 mm.

The typical method of restoration of turbine and compressor blades by a laser cladding is described in the US Patent 6,269,540 by Islam Mahmud U. wherein, a laser beam was moved relative to a metal surface and stream of metal was supplied to the surface via a supply tube. The laser beam melted a thin layer of the metal substrate and powder that was delivered to the substrate to form a band of fused metal on the surface.

Numerous other methods of repairing of turbine blades manufactured of conventional polycrystalline, directionally solidified and single crystal nickel and cobalt based alloys using laser cladding with similar and dissimilar filler materials were also disclosed in the US Patents 5,897,801, 6,659,332, 6,972,390 and 7,137,544.

However, no one of prior arts above would produce a required combination of a high straight and impact toughness of fan blades manufactured of titanium alloys due to peculiarities of polymorphous transformation, microstructure and mechanical properties of titanium alloys.

Therefore, it is an objective of the present invention to modify airfoils during repair enhancing their high impact toughness and erosion resistance as well as provide a cost effective method for repairing of airfoils manufactured of titanium alloys.

We have found that to improve impact toughness enhancing high erosion resistance and reducing a cost of a repair, an airfoil that constitute of a stub of a parent material and repair section that comprises a sequence of consecutive ductile damper alpha or near to alpha titanium layers with a total width of damper layers of 10 - 50% of a width of a repair section, and high strength structural alpha – beta or beta titanium layers that are bonded to ductile damper layers making from 50 to 90% of a width of a repair section with a width of each layer of 0.5 – 20 times of an average thickness of a corresponded section of an airfoil.

In accordance with another preferable embodiment of the this invention the airfoil also can comprise a high erosion resistance layer made of a material that is metallurgicaly compatible with titanium and bonded at least to the one of the airfoil edge by a fusion welding or cladding.

As per an embodiments high erosion resistance layers that are bonded to the tip, leading and trailing edges of airfoils can be made of gamma titanium Ti_3Al or Ti_3Ni alloys.

To prevent crack propagation from the erosion resistance layer into the airfoil in accordance with another embodiment a transition layer between the high strength structural and high erosion resistance layers is made of the alpha or near to alpha titanium alloy.

A method of repairing of an airfoil as per the preferable embodiment includes steps of:

a) machining off a damaged portion of the airfoil removing minimum required material to leave the stub of the sound parent material that is free of defects,
b) cleaning,
c) fusion multi pass weld deposition also known as cladding to the stub of the airfoil using at least two different types of filler materials made of alpha or near to alpha and alpha – beta or beta titanium alloys to produce the sequence of consecutive ductile damper and high strength structural layers with ratio of 10 – 50% and 50 -90 % respectively,
d) heat treatment,
e) machining of the repair area to from a concave and convex surfaces of the airfoil and
f) nondestructive testing of the airfoil.

In accordance with another preferable embodiment during repair each layer is produced by at least two consecutive fusion welding passes using the same filler material to reduce dilution and ensure required properties of ductile and high strength layers.

As per another embodiment, the ductile damper titanium layer is deposited directly to the stub of the airfoil to prevent cracks propagation into the airfoil.

To improve efficiency of the post weld heat treatment, the latter is made at a highest prescribed temperature for one of the selected filler materials.

Also, depending on the chemical composition of the high strengths layers the post stress relief can be done using parameters for unalloyed titanium welds.

As per another embodiment the temperature of the blade during heat treatment can be reduced from a nominal for the selected titanium alloy also known as standard in the repair area to 500° C or below of the fusion line.

To reduce the cost of rework of blades that were rejected by non destructive testing (NDT) the ductile alpha or near to alpha titanium filler material is used to repair discontinuities by a fusion welding regardless of a chemical composition of the defective layer.

To reduce grain sizes in the repaired area during fusion weld deposition or cladding of consecutive passes each previous weld deposit is cooled down by a heat sink or other means preferably to a temperature that is bellow of a temperature of a polymorphous transformation of the filler material that was used to produce a previous layer.

Further development of the embodiment above comprises the incremental offsetting of the heat sink above the center line of the previous weld deposit.

Figure 1 depicts the fan blade with impact damage on the leading edge of the airfoil and extensive erosion damage on the trailing edge.

Figure 2 shows the fan blade after removing of damaged leading and trailing edges by machining.

Figure 3 schematically depicts the fan blade after repair.

Figure 4 illustrates a cross section of a fan blade with multi layer restoration.

Figure 5 depict the cross section of a fan blade tip with the installed heat sink fixture.

Figure 6 shows the Charpy V-notch impact toughness of Ti and Ti-6%Ale-4%V alloy as per R.T. Webster and C.S. Young, Industrial Application of Titanium and Zirconium alloys, STP830, ASTM, 1984.

Figures above illustrate the preferable embodiment at different stages of a repair wherein, the airfoil 1 constitutes the leading 2 and trailing 3 edges that were prepared for a weld deposition by machining, as well as a sequence of ductile alpha or near to alpha titanium layers 4 bonded to the airfoil 1, high strength alpha – beta or beta titanium layers 5, high erosion resistance layer 6 made of alloys with superior erosion and corrosion resistance such as gamma titanium alloys that are bonded to the ductile damper layers 4, which is produced of alpha or near to alpha titanium alloy. The water cooling heat sink 7 is installed either sides of the airfoil and incrementally moved up above the center line of the previously completed weld deposit 9. The laser or GTAW or microplasma weld head 8 is positioned along the center line of the repaired section of the airfoil 1. The welding puddle is produced by the laser beam 10 in case of a laser welding or by electric arc in GTAW or microplasma welding. Filler wire 11 or powder 12 is introduced into the welding puddle using the standard wire or powder feeder that is not shown herein. The filler wire is preferable for a weld deposition or cladding considering a high affinity of titanium for oxygen and nitrogen. Titanium powders can be used for a weld deposition as well. However, exposure titanium to open air can result in brittleness of weld deposits due to contamination of a welding puddle with oxygen and nitrogen and porosity, which might be affiliated to moisture adsorption. Powders filler materials are essential for a weld deposition of high strength gamma titanium (Ti sub 3 -Al) layers.

The invented blade and method of a repair are described in more details hereafter with references to drawings above.

The leading edge of airfoils most frequently subjected to impact damage and erosion while the trailing edge is affected mostly by erosion. In case of multiple damage of a leading or trailing edge full leading edge restoration is most cost effective. Therefore, the leading edge is machined off to a depth that is just enough to remove damaged material leaving a stub of a sound parent material as shown in Figure 2. The localized damage can be removed by scalloping using a manual grinding or machining.

After machining damaged blades are subjected to degreasing, acid etching using solution made of 2-3% of hydrofluoric acid, 5-10% nitric acids and water to balance followed by water rinsing and hot air draying to remove moisture. It is also a good practice to seal blades using plastic bags and produce welding within 8 hours of chemical cleaning.

Most fan and compressor blades are manufactured of alpha-beta Ti-6%Al-4%V or near to alpha Ti-8%Al-1%V-1%Mo alloys. Therefore, as an example, selection of filler materials will be explained in more details for these alloys.

The impact toughness and ductility of titanium and near to alpha titanium alloys are much higher than Ti-6%Al-4%V and other alpha-beta alloys but in accordance with data published in "Industrial Application of Titanium and Zirconium", Third Conference, R.T. Webster and C.Y. Young, Ed., STP 830, ASTM, 1984" strength of latter is at least 2 – 3 times greater than pure titanium as shown in Figure 6.

For example, impact or Charpy toughness of commercially pure titanium varies between 170 to 220 J depending on oxygen content while Charpy toughness of Ti-6%Al-4%V is 75 - 90 J. However, the ultimate strength of these materials in the mill – annealed condition is 280 - 310 MPa and 940 - 960 MPa respectively, refer to Welding, Brazing and Soldering, ASM International, Volume 6, pp.507 – 523. Therefore, the combination of commercial purity titanium and Ti-6%Al-4%V filler materials or combination of standard near to alpha Ti-2.5%Cu or Ti-5%al-2.5%Sn and Ti-6%Al-4%V filler materials can be used for a repair of fan blades manufactured of Ti-6%Al-4%V and Ti-8%Al-1%V-1%Mo alloys.

The precision laser weld deposition or cladding, microplasma weld build up, automatic and manual gas tungsten arc welding (GTAW) can be used for a repair of fan blades. However, the best result could be achieved by a laser weld deposition also known as laser cladding that is capable to produce net shape welds with the excessive material exceeding of thickness of airfoils just by 0.15-0.25 mm per side. Also, this method can significantly reduce dilution of alloying elements in the high strength structural and ductile damper layers. Welding parameters should be selected to perform a weld deposition in a cladding mode with minimum melting of previous deposits. The GTAW weld bead excess can vary from 0.5 to 2 mm, which is still noticeably les that a standard patch of 12.5- 15 mm in thickness.

The copper or water cooling heat sinks might be used to reduce a temperature of the previously made weld deposits to control grain growth. The best result can be achieved if a temperature along a fusion line of the previous weld deposit is below of the temperature of polymorphous transformation or 800° C for Ti-6%Al-4%V alloy. To maintain this temperature the heat sink should be incrementally brought up above the center line of the previous deposit as it shown in Figure 5. Also, weld deposition should be made using minimal heat input.

To prevent crack propagation into airfoil through the repaired area the first layer 4 shown in Figure 3 should be made using the ductile pure titanium or near to alpha titanium filler material. This layer will accommodate excessive stresses by a plastic deformation and prevent crack propagation into the parent material.

It was found that to prevent crack propagation the optimal width of ductile layers should be at least three (3) times greater than their thickness. The impact toughness reached a plateau at the width of ductile layers of 3 – 5 times greater than thicknesses of samples. Due to variability of blade thicknesses, which is progressively reduced from a stacking axis to the leading and trailing edges, it is appropriate to use an average thickness of the airfoil at corresponded sections and limit the width of these layers to a max of 20 thicknesses of airfoil ensuring balance between ductility and structural strength of blades. The diagram of the repaired section of the fan blade is depicted in Figure 4, wherein the width of the layer 5 in the section B_5 can vary from $0.5 \times H_5$ to $20 \times H_5$.

Pure titanium as well as near to alpha titanium alloys have lower than Ti-6%Al-4%V alpha-beta alloy erosion resistance. Hans, due to produce acceptable combination of impact toughness, strength and erosion resistance further weld deposition to the leading and trailing edge can be done using Ti-6%Al-4%V (AMS 4956) filler material. The most advanced embodiment of the invented method produces the consecutive sequence of the high strength structural and ductile damper multi layers. The size and amount of alpha and alpha-beta or beta layers should be two or divisible by two. The total ratio of layers should constitute from 10 to 50 vol. % of ductile damper alpha and from 50 to 90 vol. % of structural alpha-beta or beta titanium layers.

The high erosion resistance of alpha-beta titanium alloy should be applied to the tip of the blade to restore overhaul length.

Another advanced embodiment of the invented method is shown in Figure 4, wherein the high were resistance layer 6 of beta or gamma titanium (Ti_3Al or Ti_3Ni) alloy is deposited directly onto the fan blade leading edge.

Gama titanium has unique combination of high strength and erosion resistance. However, this material has low ductility and impact toughness. Therefore, to prevent the airfoil failure in case of impact damage or FOD, the gamma titanium layer should be deposited onto the ductile alpha or near to alpha titanium layer as shown in Figure 4.

In a process of a repair dimensions of an airfoil might be continuously monitored using a standard laser measurement system, which can be incorporated directly into a weld deposition system, that in combination with a computerized weld programming and visual system will allow to produce near to a net shape weld deposition.

After welding, fan blades are subjected to degreasing and heat treatment in vacuum or argon using parameters for welded joints of Ti-6%Al-4%V alloy at a temperature of 580 - 650 Deg. C for four (4) hours while a recommended heat treatment temperature for a commercially pure titanium welds can be only 595 Deg. C. As a result, these fan blades can be subjected to a full standard furnace heat treatment. No damage will be done neither to a parent material no to alpha titanium layers.

In case of using of Ti - 13.5%V - 11%Cr – 3%Al (AMS 4959) beta or Ti_3Al gamma titanium alloys to produce a high erosion resistance layer on a leading or trailing edge of fan blades, the nominal stress relief temperature is 760 - 815 Deg. C. It is significantly higher that a nominal or standard heat treatment temperature for Ti-6%Al-4%V welds. Therefore, to produce full post weld stress relief of these welds without damaging of a parent material a temperature of a fan blade should be gradually reduced from 815 Deg. C in a welding area to 500 Deg. C or less in a parent material below of a fusion line.

The final machining and polishing of airfoils aim to restore required shape, dimensions and surface roughness. These operations are carried out using the standard CNC milling machines and polishing.

To allow reliable NDT inspection of fan blades latter must be subjected to alkaline degreasing and acid etching to remove smear materials, open surface defects if any and remove oxidation followed by water rinsing and air drying.

The NDT inspection of fan blades consists of standard fluorescent penetrant (FPI), x-ray and Eddy current (ED) inspections that should made to the relevant AMS or OEM Engine Manual standards. Usually, no linear indications, pores exceeding of 0.25 mm in diameter and chain porosity are acceptable. Rejected indications should be blended out using the standard carbide burr followed by a fusion welding. However, to avoid cracking the ductile alpha and near to alpha titanium filler materials should be used to weld all defects regardless on the chemical composition of defective layers aiming minimize the cost of rework, standardize a repair procedure, and reduce risk of cracking of high strength and erosion resistance layer.

The final stage of a repair of blisks, fan and compressor blades includes glass bead peening of airfoils, shot peening of dovetail, vibratory polishing of airfoils to achieve roughness of 22 – 26 microns on a concave and 32 - 36 microns on convex side and moment weight that should be done in accordance with a corresponded Engine Manuals. Therefore, these operations will not be discussed hereafter.

To validate the invented repair method test coupons of 2 mm in thickness were produced of Ti-6%Al-4%V alloy. Number of passes varied from 1 to 10.

In process of experiments it was found that disregard on a method of a fusion welding each layer should be made using at least two passes to control dilution. However, the best results were achieved using three passes as it was mentioned above.

Prior to welding, test coupons and filler material were subjected to a chemical etching in mixture of water, hydrofluoric and nitric acids, rinsed in the demilitarized water and alcohol.

Commercially pure titanium and Ti-6%Al-4%V filler wire of 1.0 mm in diameter were used to produce weld deposits with following below sequence of ductile damper, high strength structural and high corrosion resistance layers:

- Titanium - Ti-6%Al-4%V
- Titanium - Ti-6%Al-4%V - Titanium - Ti-6%Al-4%V

After welding test coupons were subjected to a heat treatment in vacuum of 0.5 torr at a temperature of 650 Deg. C for four (4) hours followed by a furnace cooling.

The parent material, heat affected zone, each pass and layer of weld deposits were subjected to microhardness and bend test of notched welds to evaluate ability of a repair area withstand crack propagation during bending that is typical for a foreign object damage of fan blades.

An average microhardness different layers that was produced using three (3) consecutive pass is shown in the table below:

Material	Average Micro Hardness, HV
Parente Material (Ti-6%Al-4%V)	320
Pure Titanium Weld Build Up	210
Ti-6%Al-4%V Weld Build Up	312

Based on the foregoing, the objectives of this invention was achieved by creating of a composite-like multi lamellar structure in the repair section of an airfoil constituting of the ductile alpha titanium damper and high strength structural alpha – beta layers.

Claims:

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

1. An airfoil constituting of a stub of a parent material and repair section that comprises a sequence of consecutive ductile damper alpha or near to alpha titanium layers with a total width of 10 - 50% of a width of a repair section, and high strength structural alpha – beta or beta titanium layers that are bonded to ductile damper layers making from 50 to 90% of a width of a repair section with a width of each layer of 0.5 – 20 of an average thickness of a corresponded section of an airfoil.

2. The airfoil as per claim 1 comprises a high erosion resistance layer that is made of a material, which is metallurgicaly compatible with titanium, and bonded at least to one of the airfoil edge by a fusion welding.

3. The airfoil as per claim 2, wherein at least one of the airfoils edges constitutes the erosion resistance layer made of a gamma titanium alloy.

4. The airfoil as per claim 3, wherein a transition layer between the high strength structural and high erosion resistance layers is made of the alpha or near to alpha titanium alloy.

5. A method of repairing of the airfoil as per claim1includes steps of:

   a) machining off a damaged portion of the airfoil removing minimum required material to leave the stub of the sound free of defects parent material,
   b) cleaning,
   c) fusion multi pass weld deposition or cladding to a stub using at least two different filler materials made of alpha or near to alpha and alpha – beta or beta titanium alloys to produce the sequence of consecutive ductile damper and high strength structural layers with a ratio of 10 – 50% and 50 -90 % respectively,
   d) heat treatment,
   e) machining of the repair area to from a concave and convex surfaces of the airfoil, and
   f) nondestructive testing of the airfoil.

6. The method of repairing of the airfoil as per claim 5, wherein each layer is produced by at least two consecutive fusion welding passes using the same filler material.

7. The method of repairing of the airfoil as per claim 5, wherein the ductile damper titanium layer is deposited directly to the stub of the airfoil.

8. The method of repairing of the airfoil as per claim 5, wherein the post weld heat treatment is made at a highest prescribed by relevant standards for the selected filler materials temperature.

9. The method of repairing of the airfoil as per claim 8, wherein the temperature of the blade during heat treatment is reduced from the standard or nominal in the repair area to 500° C or below in the parent material along a fusion line.

10. The method of repairing of the airfoil as per claim 5, wherein the post weld heat treatment is made using parameters that are prescribed by the relevant standards for a stress relief of unalloyed titanium welds.

11. The method of repairing of the airfoil as per claim 5, wherein the ductile alpha or near to alpha titanium filler material is used to repair discontinuities regardless of a chemical composition of the layer contained defects.

12. The method of repairing of airfoils as per claim 5, wherein during the fusion weld deposition of consecutive passes each previous weld deposit is cooled down to maintain a temperature along it fusion line bellow of a temperature of a polymorphous alpha – beta transformation.

13. The method of repairing of the airfoil as per claim 5, wherein cooling of subsequent welds is produced by a heat sink that is incrementally moved above of a center line of the previous welds.

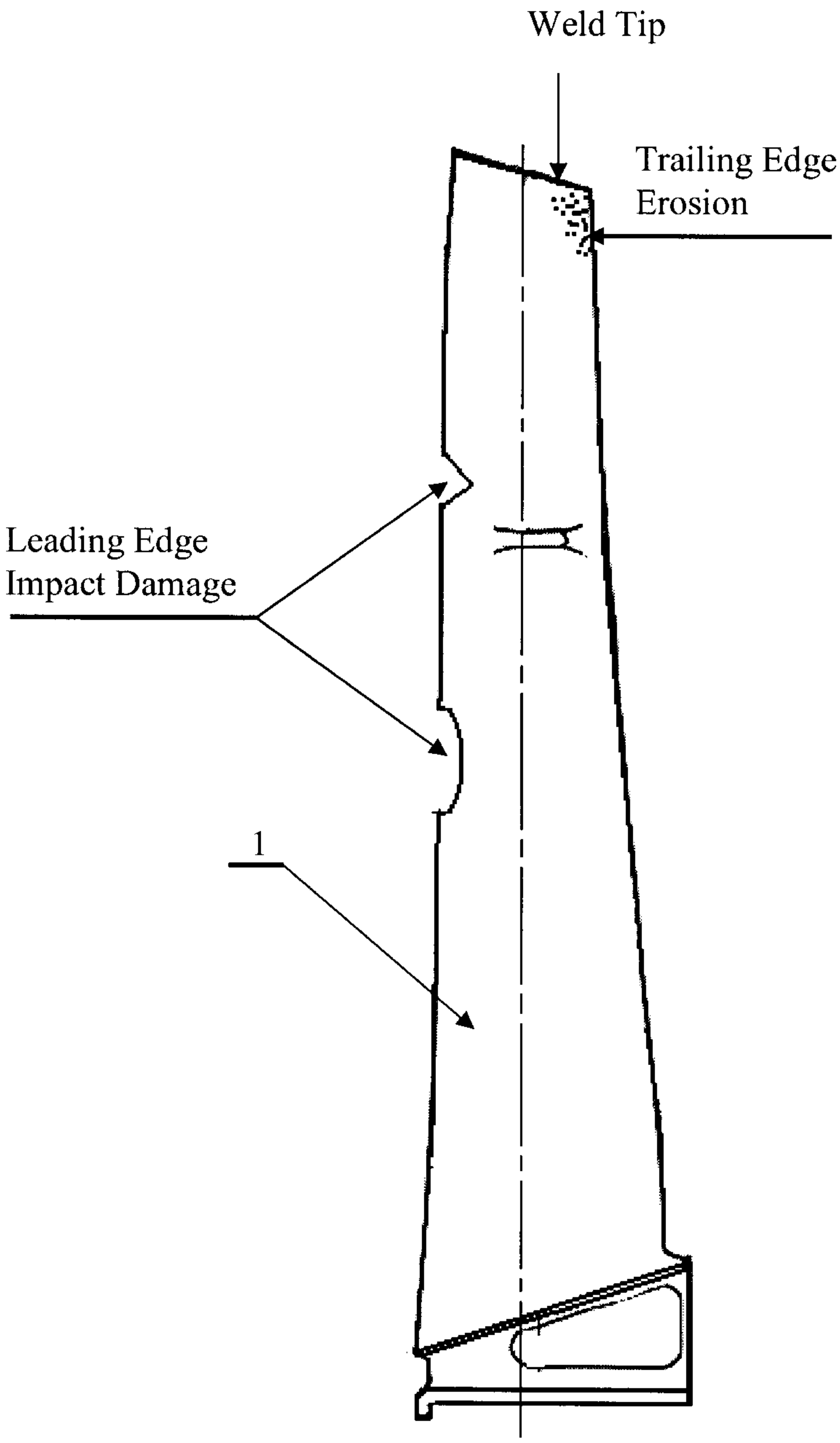

Weld Tip
Trailing Edge
Erosion
Leading Edge
Impact Damage
1

Figure 1

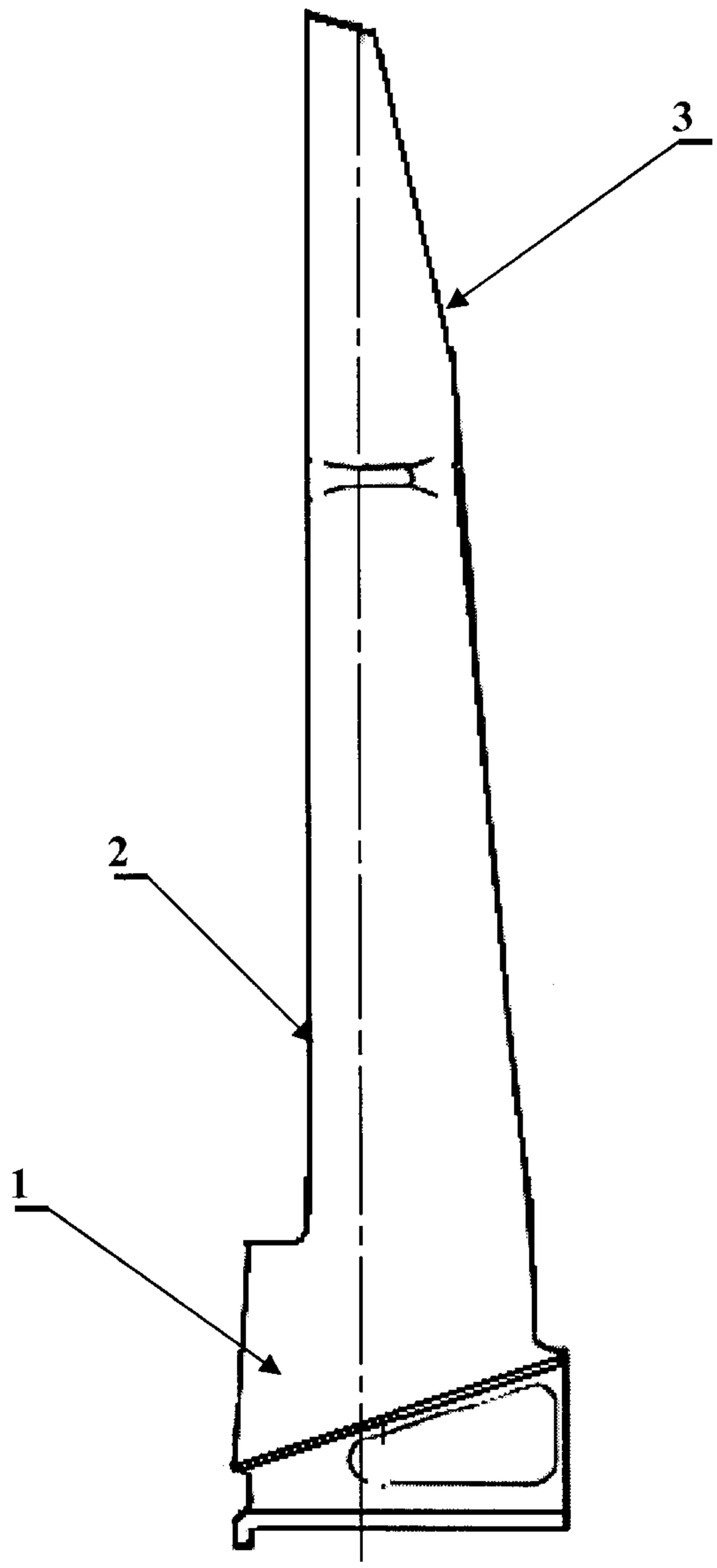


Figure 2

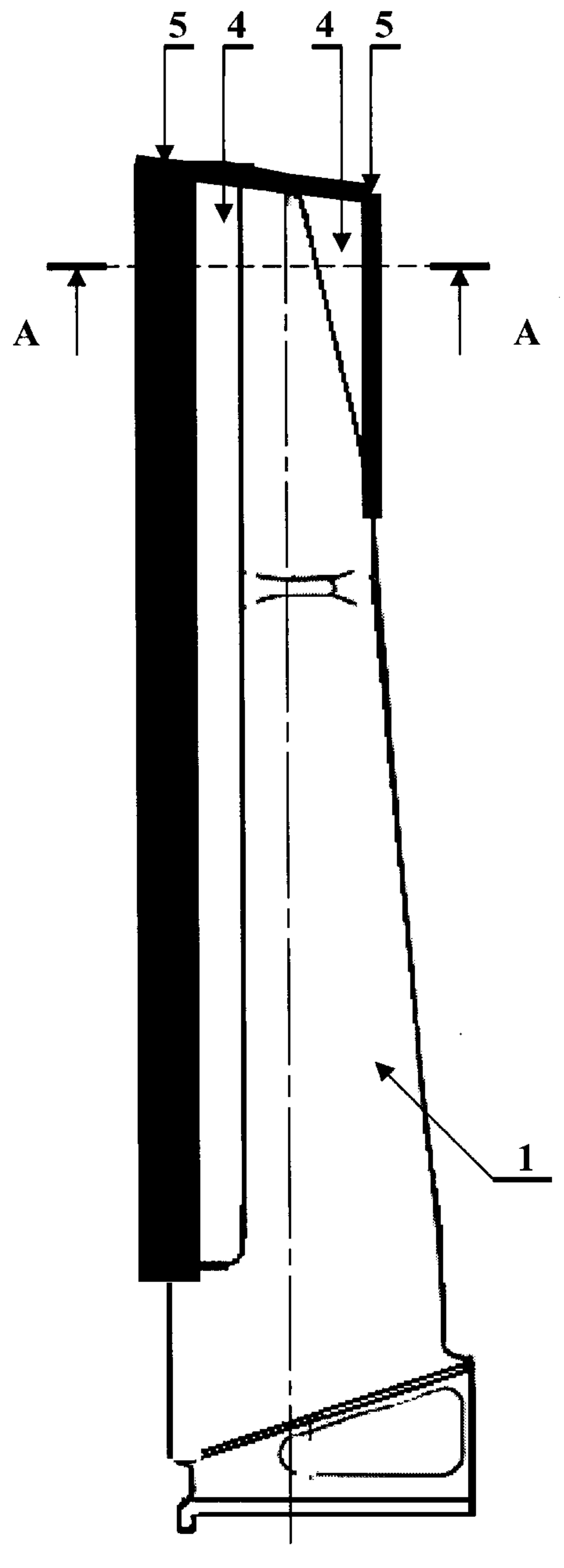


Figure 3

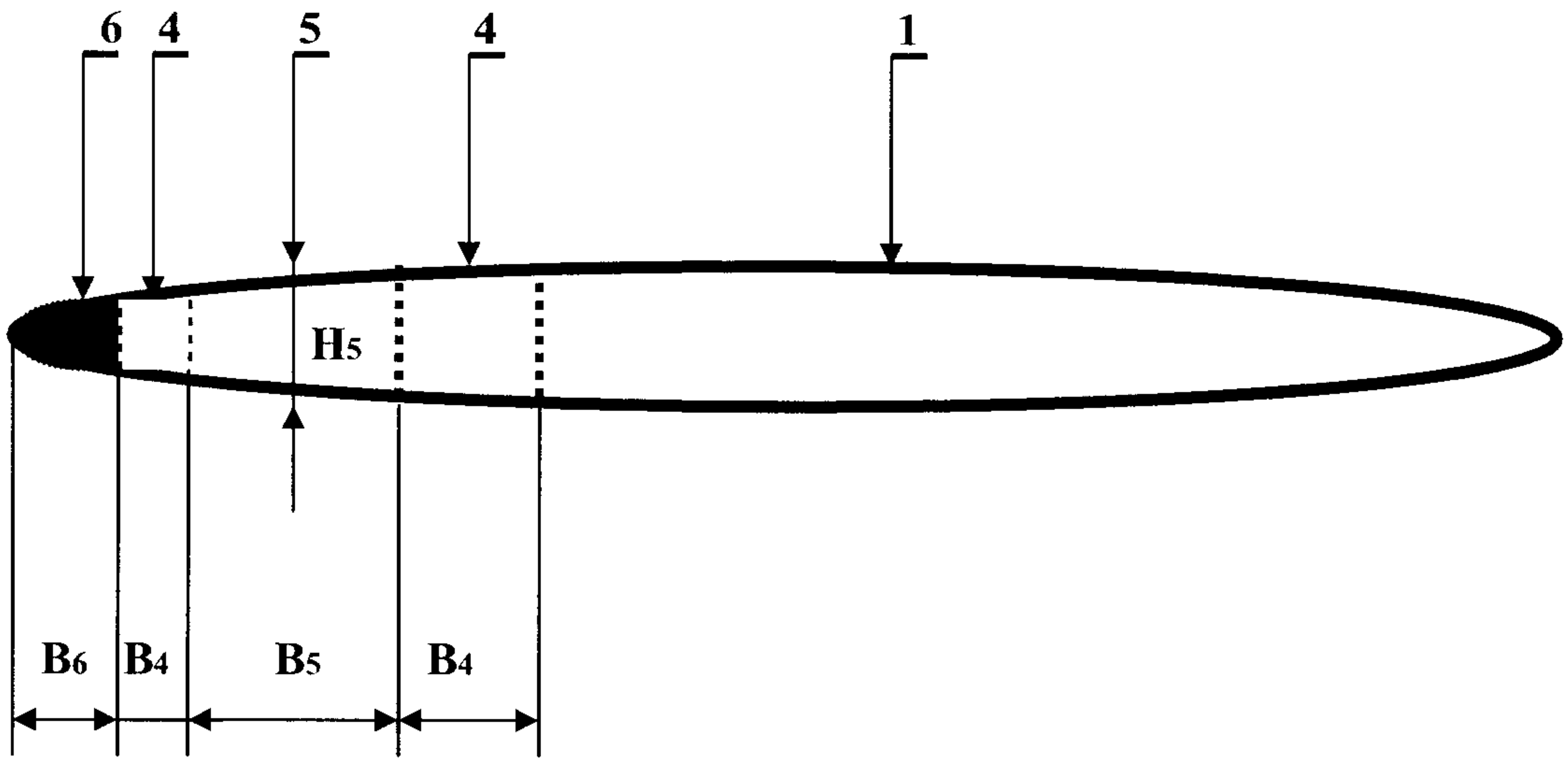


Figure 4

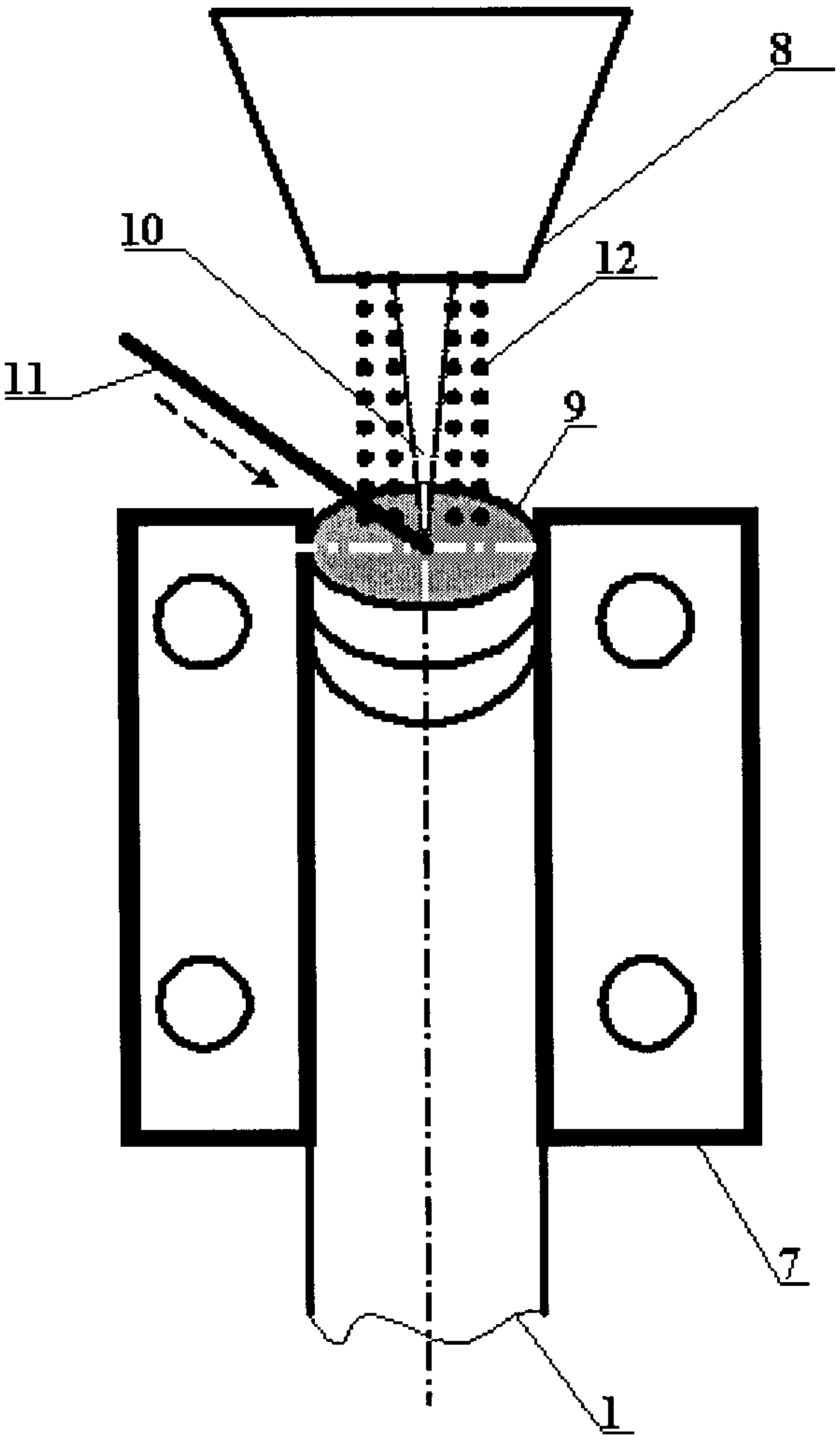


Figure 5

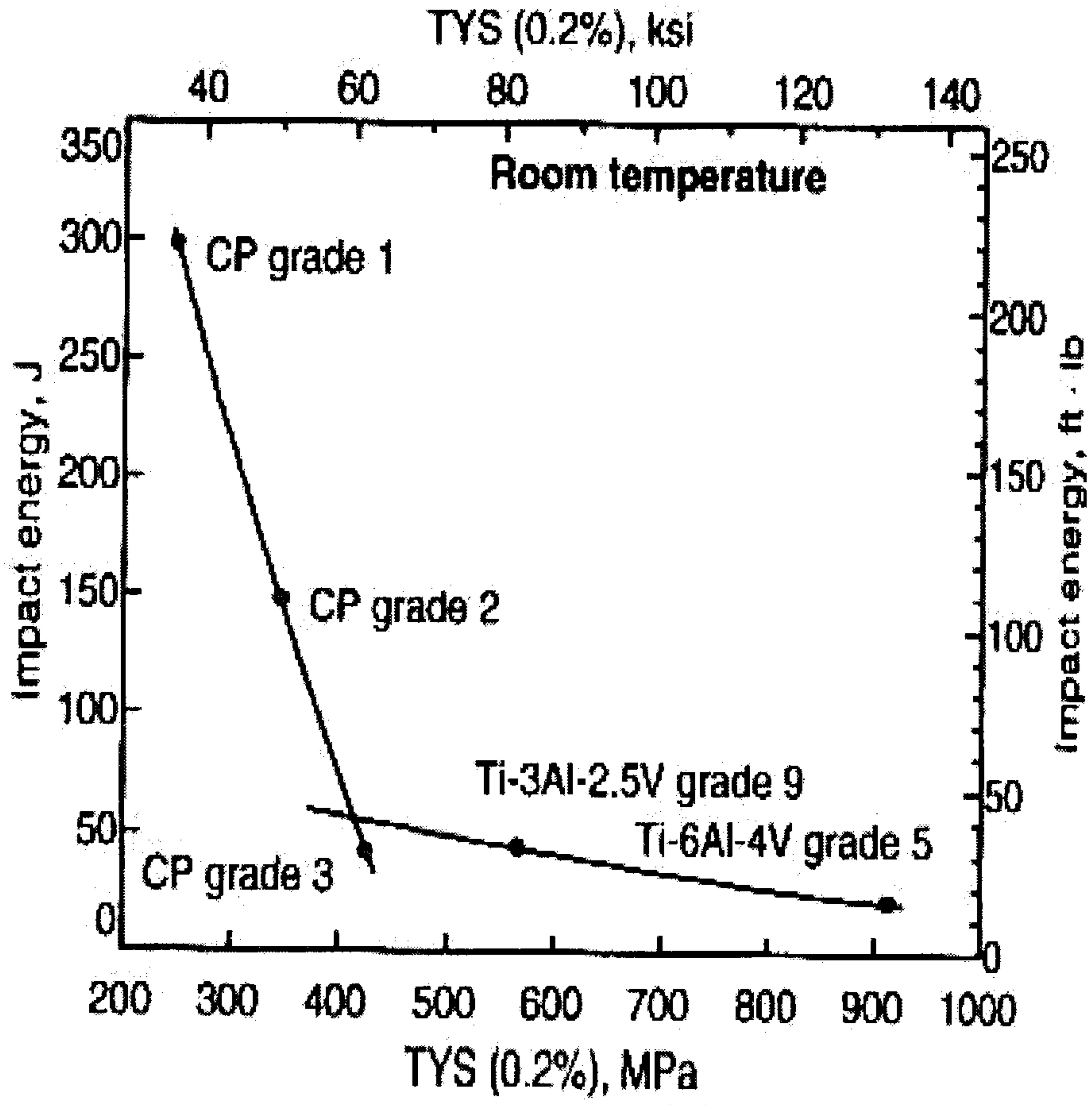
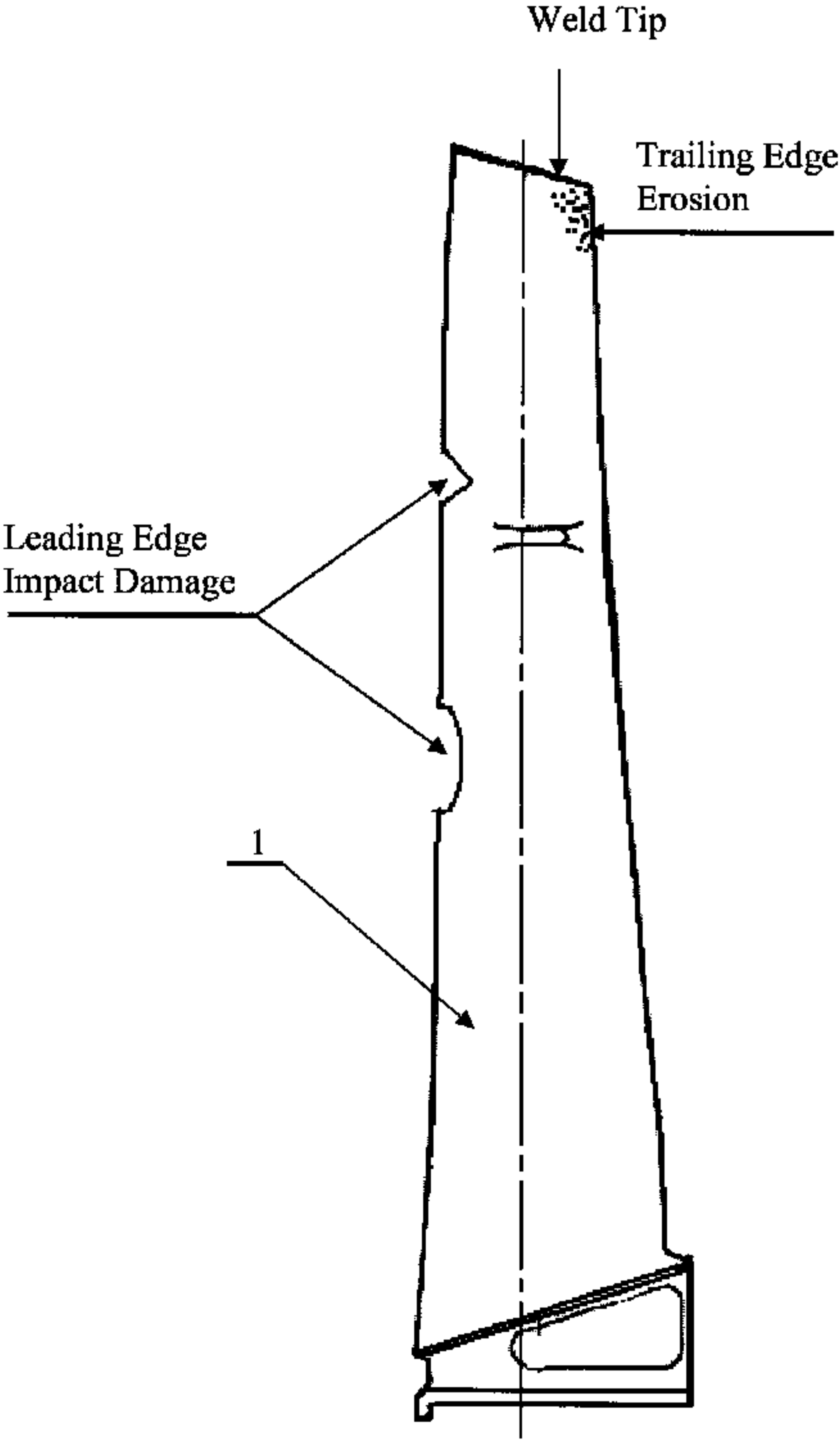


Figure 6
Charpy V-notch impact toughness vs. yield strength of titanium and Ti-6%Al-4%V alloy as per R.T. Webster and C.S. Young


Weld Tip
Trailing Edge
Erosion
Leading Edge
Impact Damage
1