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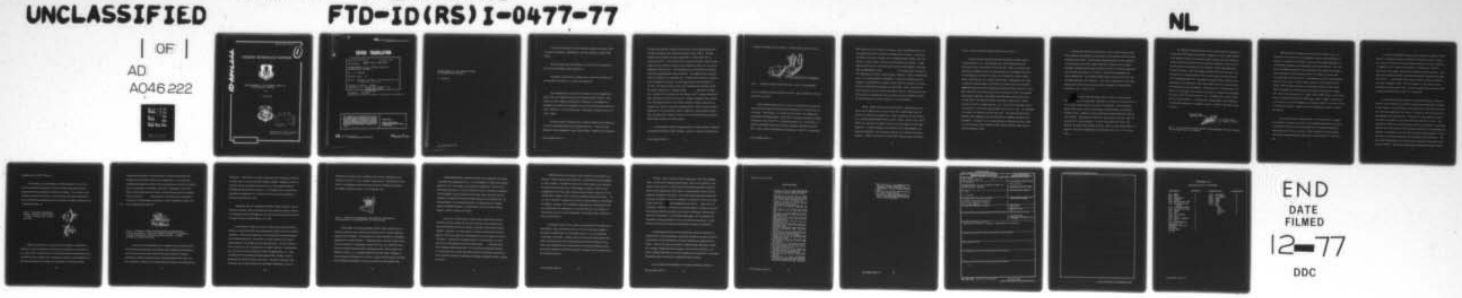

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by

J. Lunarski

EDITED TRANSLATION

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REINFORCEMENT OF GAS TURBINE BLADES
BY TECHNOLOGICAL METHODS

J. Lunarski

The article discusses the more important methods and means which increase the durability, dependability, and heat resistance of gas turbine blades.

New materials from which blades are constructed are discussed as well as the technology of their manufacture.

Following, the protective coatings used to reinforce the blades and increase their resistance to corrosion are presented.

The working blades of gas turbines belong to the most weighted elements of aircraft engines limiting their durability between repairs. They operate on small weights stretching and bending from centrifugal force, bending and turning from aerodynamic force as well as thermal and vibratory loads. Moreover, they work under high temperature conditions and in corrosion media.

The basic method currently used to reinforce blades is the elaboration of the new and modernization of the existing materials. There are many patents for alloys designated for gas turbine blades. Thanks to the excellence of blade materials the average yearly increase of the working temperature of blades during the last 15 years amounted to nearly 7-8° C. Working temperatures of blades presently equal 960° C, turbine disks 735° C, flame-tubes 870° C. An increase can be observed of the Co content in blade grades but the combined content of such components as Mo, Nb, Ta, and Ti approaches 15% and more. Great perspectives are betokened by composite material containing reinforcing metal fibers. An example can be material which is composed of 3 components (1): 10-20% metal warp from a rhodium alloy (composition not given), 40-70% tungsten fibers with a diameter of 12.5 μm covered with a layer of SiC with a thickness of 45 μm and 30-50% SiC grains, spherical or irregular having diameters of 75 μm. The resistance of this material to stretching at 1315° C equals 70 kG/mm^2, while the blades can work of for 200 hrs. Another composition (2), contains up to 70% tungsten fibers covered with a protective coating, while the rest consists of an alloy in a Ni warp containing 25% W, 15% Cr, 2% Al and 2% Ti. Elaboration of such materials requires a high level of metallurgical technology, and lasts about 5 years, but the costs of the elaboration by specialized laboratories reaches 4-6 million dollars.

A considerable number of patented alloys are heat resistant, hardened by dispersion and with ceramic coatings. Alloys in a niobium warp with heat resistant coatings are also proposed. Turbine blades can also be made

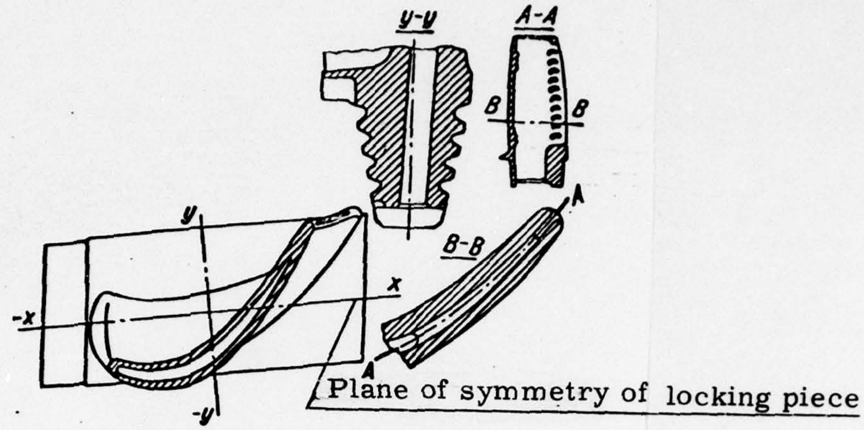

Fig. 1 Example of blade construction with a central cooling passage

by the technology of powder sintering, however, their resistance to stretching is still too small.

Heat resistant alloys cast in a vacuum or in protective atmospheres by the investment pattern method found wide application in blade production technology. This enables, in a relatively easy manner, the configuration of systems of cooling passages, which effect a lowering of the blade working temperature about 100-150° C, in using working air of 1-1.5% (3) (Fig. 1). Costs of cast blades made from the alloys Vacumelt ATS 281-G and ATS 391-6, able to endure instantaneous temperatures to 1050° C in comparison with forged ones, were subject to decrease, while such high perfection can be obtained that further mechanical working is not necessary. From these viewpoints, almost all the parts of the rotating assembly (disks of the compressor, turbine, blade, and others) can be made by this method. A high degree of perfection is achieved by perfecting the model masses, removing them by light flashes, using cores pickled after casting, etc. The technology of precision casting makes it possible to obtain a blade having a set, very useful granular arrangement, in which the boundaries are set parallel to centrifugal force, thanks to which yield and resistance increases (in the alloy MAR-M-20 elongation increases 20%). Some of these alloys have a structure close to a dual or pseudodual eutectic. With precise control of the speed of crystallization they can form so called composite materials (in solid solutions intermetallic phases or various carbides).

Of late, blades are made from monocrystals. Monocrystal blades can be cast in light-section ceramic forms with a cooled copper base in a vacuum or protective atmosphere (4), or also in induction vacuum furnaces, e.g., the alloy MAR-M-200 (0.13% C, 9% Cr, 12% W, 1% Nb, 5% Al, 2% Ti, 10% Co, the rest Ni) is by siphon cast into a form through a coil with right angles (5). A multiple change in the direction of the crystallization front blocks the expansion of all the grains except for one, which fills the blade capacity. At 980° C and stress of 21 kG/mm^2 a regular blade can work for

35 hrs., while a monocrystal blade operates for 105 hrs [5].

Good serviceable properties are also displayed by blades made of several elements, e.g., the heat-endurance alloys B1900 and Rene 80 with layers of the alloys Udimet 700 and TD NiCr, which are soldered and welded by a diffusion process, so that inernally the air passages remain (6). The locking piece and leaf of the blade can be made from various niobium alloys, then these parts are welded electronically, comparatively the edges of attack and trailing edges of the blade can be made from the intermetallic phase NiAl (the purity of the components should be 99.99%), while the central part of the blade can be made from a heat resistant alloy with an air passage and joined by soldering. Such blades work dependably within temperatures of 1204-1374^{o} C and withstand sudden temperature changes well. Blades can also be made of a single material, e.g., from several thin plates having a thickness of 0.5 mm with openings ϕ 0.3 mm every 0.5 mm. The openings in the plates are displaced towards each other. The plates are fastened by welding in the locking piece and the cooling air is supplied through the lock openings(7). Closing the cast cooling openings can take place by pins, made of an alloy having a linear expansion factor greater than the blade material, and electronically welded.

Several heat endurance alloys used for turbine blades require proper heat treatment which depends on the property of the material and the working conditions of the blade. A particularly important problem in heat treatment is the protection of the alloy surface from the corrosive action of oxygen, hydrogen, nitrogen and other gases and the protection of the alloy components from burning, particularly Ti, Al and Cr, which flows analogously with decarburization (8). Alloy additives which improve heat endurance (W, Mo, V) usually aggravate heat resistance. From these viewpoints for every alloy during heat treatment the proper protective atmosphere, heating methods, parameters, etc., must be used.

More and more often the method used to reinforce turbine blades, and in particular to increase their resistance to corrosion is various protective coatings, which usually are brought on by diffusion. The fundamental agents which cause corrosive deterioration to blade surfaces are oxidation of blade surface, sulphuric corrosion effected by exhaust gases and temperature variation. The presence of Mo in the alloy hastens corrosion, while the presence of Cr and Al lessens it. If there is less than 5% Cr then in the presence of aqueous salt solutions in the air, point corrosion of the blades [9] appears, which can be eliminated by introduction of Al, Ti, or Cr to the top layer.

The diffusion coating most often used is calorizing for the purpose of setting up a NiAl P phase, which protects against corrosion at high temperatures, against erosion at great speeds of gas, improves the heat resistance of parts made from Ni alloys and increases the resistance to sea corrosion. Ni alloys with an Al coating are more sensitive to shock loads than alloys without the coating. Pack calorizing is conducted the most often (10), (11). The process of calorizing blades from Ni and Co alloys can be performed in the following manner (11): the blades are cleaned first by steam jet with an abrasive, then chemically, after which they are put into a box and sprinkled with grains of the composition: 15% Al particles, 0.5% ammonium bromide, the rest Al_2O_3; they are put into a furnace, in which in an atmosphere of argon at 1100° C they are kept for 1 hr., attaining a layer having a thickness of 0.025-0.038 mm. To improve the coating quality a heat treatment is conducted depending on a soaking for 30 min. at 1100° C and rapid cooling in the air.

Fig. 2 Cross-section of blade leaf with cooling passages and small openings for discharge of air to the outside

Multicomponent coatings can also be used for reinforcement. An example of such a protective coating against oxidation and sulfurization of blades is a coating with Al and Mn, in which the percentage composition of both elements depends on the composition of the blade alloy (12). The coating can be applied in grains or the components of the coating can be applied electrolytically onto the protective surface, the surface is covered with the proper paste, and then anneals. The thickness of such a covering should equal 0.015-0.15 mm. Turbine blades made from cobalt alloys SM -302, WI-52, X-40 are reinforced with a tricomponent coating of Cr + Al + Mg, which are applied by a diffusion process in grains (13) having the composition: 1% Cr, 2% of the alloy Al — 15 Mg, 0.005-0.008% $CrCl_3$, 0.001-0.005% iodine or ammonium iodide and 95-98% Al_2O_3, kaolin or MgO. The process is carried on in a neutral atmosphere or hydrogen at 980° C to achieve a layer of 25-125 μm thickness. Blades with such a coating can operate at 1150° C for 100 hrs.

Use of blades made of niobium alloys, on which protective coatings are necessary, permits an increase in the working temperature of the blade of $120-150^\circ$ C (3) while the currently high costs of manufacturing them by mass production can be cut 10 times. Tests conducted reveal that blades with proper coatings withstand temperatures of $1100-1200^\circ$ C for 100 work hrs.

Currently the possibility is also being considered of using for turbine blades or covering them with such protective materials as silicon carbide SiC, which is characterized by great heat resistance, low linear coefficient of expansion, and it retains its properties to a temperature of 1370° C and silicon nitride Si_3N_4, which resists oxidation and thermal shocks, has particularly valuable physical-mechanical properties in temperatures higher than 1100° C. Turbine guide-vanes made of silicon nitride are produced by powder moulding at 1500° C with the addition of 1.5% metal, and then grinding by a diamond wheel (14). Tensile strength of this material at 1200° C equals 70 kG/mm^2 and at 1375° C — 32 kG/mm^2.

A method which makes possible a considerable increase in gas temperature in the turbine is the perfected cooling system depending on making a large number of small openings in the concave and convex side of the blade leaf, which (openings) effect the outflow of cooling air from the internal cooling passages to the blade surface. The number of such openings can reach up to 500 in one blade (15), and their dimensions ∅ 0.25 x 6.3 mm. The openings are made by an electromagnetic method on a machine tool especially made for this, which effects the simultaneous production of 100 openings, and with that, the thickness of the layer with structural changes equals 0.12 mm, which does not influence essentially the worsening of blade resistance. The use of such blades effects an increase in the temperature of the gases in the turbine to 1260° C, while under experimental conditions the blades worked satisfactorily at 1430° C (Fig. 2).

The durability and dependability of blades depends not only on material and constructional factors, but also on many technological factors associated with the mechanical working of the blades. The condition of the surface layer (SL) of the blades, and traces of the preceding working influence essentially the longlimiting stress and fatigue strength during the period of exploitation (Fig. 3).

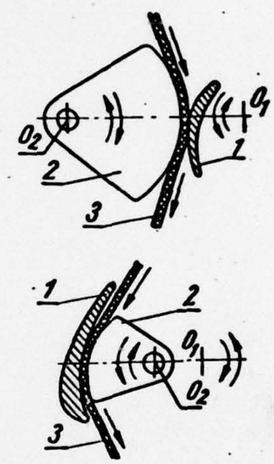

Fig. 3 Principle of grinding of profile of blades by abrasive belt: 1-blade, 2-profile cam, 3-abrasive belt

Many tests which were conducted made it possible to establish the influence of various methods and parameters of working on the condition of the surface layer, and particularly on the hardening (also called surface cold work) and internal stresses (16). Knowing the character of the dependence of the endurance properties of blades on the quality of the surface and the characteristic qualities of the alloys used, the optimal parameters and methods of the working of blades can be determined. As a result of the mechanical and thermal reaction of the machining tool on the SL of the blade there can take place a refinement of structure, hardening, a rise in the blade of unfavorable internal stresses, which phenomena cause an intensity of the processes of atom diffusion, the firing of alloy components, lowering of recrystallization temperature, which consequently leads to premature blade deterioration (8).

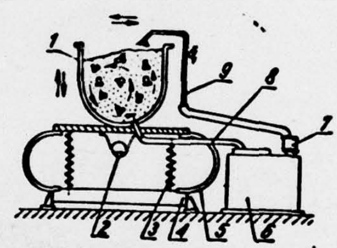

Fig. 4 Schematic of blade vibration-abrasion polishing device: 1- working container, 2-shaft with unbalanced mass, 3, 5-suspension springs, 4-base plate, 6-abrasive mixture container, 7-pump, 8, 9-ducts for liquid circulation

On account of the instability of the conditions of the working and physical-mechanical properties of the material after analogical working operations various sizes and distributions of internal stresses are obtained. During the working of moulded surfaces individual places of the object can have a different condition in SL considering the fluctuation of interoperational allowances. Tests which were made reveal that such irregularity of internal stresses leads to a clear lowering of fatigue strength. Regularity of the SL condition can be considerably improved by use of the proper methods of finishing and reinforcement, however, it is necessary here to consider the possibility of inheritance of the condition of the surface layer attained in previous operations (17), (18).

Operations such as: polishing and abrasive-blast treatment, electrochemical treatment, blast cleaning and vibration polishing belong to methods of working which form advantageous stress distribution and which provide for evenness of the SL condition (Fig 4), (17), (19).

A favorable SL condition can also be achieved by processes such as: milling, turning and abrasive belt grinding under proper selection of working conditions. Of particular importance are mechanization and automatization of the finishing operation, which effect increased stability of the surface quality achieved, as compared with manual operations. An even reinforcement of the SL can also be achieved by an adapted operation. during machining or the use of various methods of surface burnishing (Fig. 5) -- blast cleaning (17), jet burnishing with glass spheres (20), rolling, vibration polishing (19), vibration rolling, and others. The above methods of reinforcement can be used exclusively for the blade locking piece, since its temperature during the time of operation does exceed, depending on the material, 450-700^{o} C, since at higher temperatures, considering the lowering of recrystallization temperature and the force of diffusion processes, the fatigue strength is subject to a decrease (8), (17).

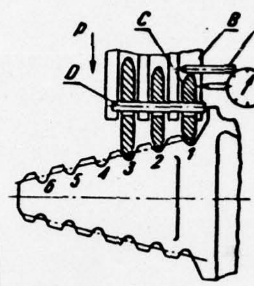

Fig. 5 Schematic of burnishing of rows of blade locking pieces: A-setting device, B-burnisher body, C-roller, D-axle

Unfavorable stress and hardening of the SL which is effected by mechanical treatment can be avoided by introduction of the proper additional tempering after finishing. The parameters of such treatment are designated depending on the blade material. Tempering effects a smaller tensile stress, and even attainment of compressive stress in the SL, but it should be introduced in conditions which exclude worsening of the SL, which is often very difficult to attain, e.g., heating the EI617 alloy in air leads to changes of microhardness the thickness of 0.15 mm, in argon 0.05 mm and in a nitrogen mixture (96%) and hydrogen 0.035 mm because of two-side diffusion (8).

Under exploitational conditions because of the evaporation and firing of several alloy components (Al, Ti, Cr) and diffusion of atoms from exhaust gases (S, N, H, O) a change in the chemical composition of the SL and its properties takes place on account of which the linear coefficient of expansion of the SL differs from the material of the warp, which can lead to the constitution of considerable internal stresses during time of operation (8). By this phenomenon we can partially prevent, by using protective coatings applied by diffusion methods, by metallization, the use of heat resistant enamel, ceramic coatings, and others.

From here it follows that to reinforce gas turbine blades various methods are used, among which the most important ones include the perfection of materials used for the blades, elaboration of new alloys having valuable properties, an endeavoring for maximum stabilization and homogeneity of these materials and a minimalization in the the number of structural defects. Preliminary moulding of blades, often and finally, can take place both via blocking and precision casting under conditions which favor attaining optimal properties. For every newly elaborated material it is necessary also to select the proper method of producing the particular cuts of thermal treatment—hardening, tempering, heating for plastic working, and others.

Diffusion protective coatings on blade surfaces are particularly perspective, considering their good adherence, considerably better than applied by other methods. A gradual decrease in the concentration of the coating in the bulk of the material favors a fluid change in property, while in other coatings there is a violent skip of those properties which causes the rise of considerable stresses, which can lead to premature blade deterioration. Al, Cr, Mo, W and other coatings can be used for turbine blades or multicomponent diffusion coatings. The technology of applying such coatings should take into consideration the properties of a concrete material, the conditions of its operation in service and the possibility of using them under conditions of direct-line production.

Considerable effects can be achieved by perfections of the blade cooling systems, which nevertheless often tie in with construction changes of the engine and difficulties of a technological nature, e. g., the formation of openings in the blades. Thanks to the use of electroerosion method treatments, and particularly electrospark hollowing and electrochemical treatment, these difficulties can be resolved from a technical standpoint as well as from the standpoint of selecting methods of manufacture for requirements of a flowing production.

Because, under conditions of high temperature, static and changing loads, a substructure having minimal energy, which in turn depends on the plastic strain of the SL, is characterized as having the greatest resistance, then for every temperature there exists a certain optimum strain ensuring maximum resistance of the alloy. For turbine blades operating at high temperatures the optimum, from the standpoint of resistance, will be very small strain of the order 1 , fixed depending on the type of alloy and work conditions. From these viewpoints in a suitable manner, methods of mechanical treatment should be selected, particularly of finishings, endeavoring to achieve even allowances, total and interoperational, and to mechanize and automatize working processes in order to stabilize the properties of the SL attained, as well as observing the technological discipline of production.

In planning perspective tests the possibility should be considered of readjustment of working methods or individual operations for mass production requirements and the possibilities created by equipment and apparatus possessed. Tests of the various processes of blade casting, application of diffusion coatings, forging with great energies, electroerosion treatment, and others, demand large inputs, the latest equipment and a high level of knowledge and specialization of personnel occupied with these problems.

A more extensive bibliography on the above mentioned problems is given in the work (21).

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