

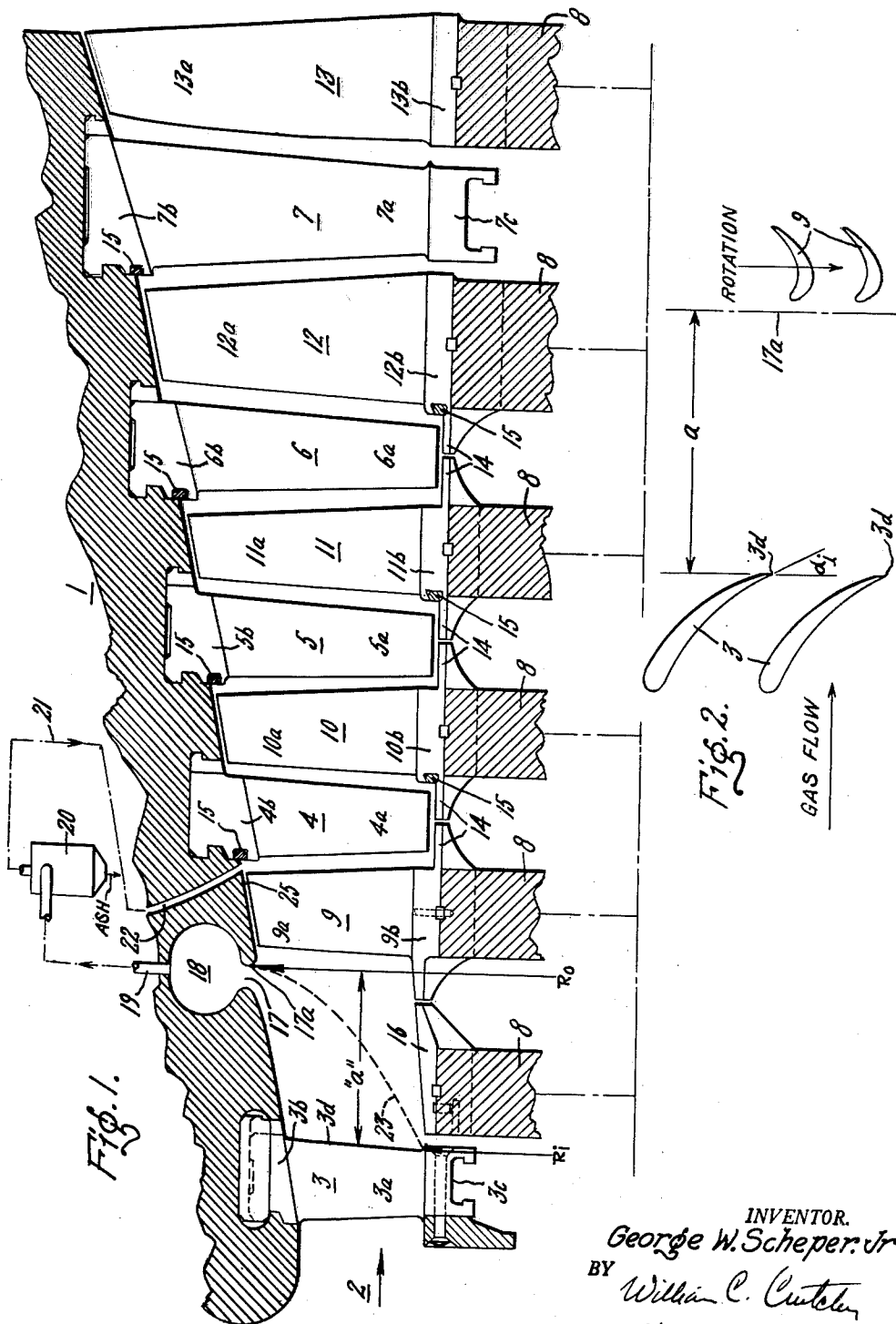
Dec. 4, 1962

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3,066,912

TURBINE EROSION PROTECTIVE DEVICE

Filed March 28, 1961



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TURBINE EROSION PROTECTIVE DEVICE

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Filed Mar. 28, 1961, Ser. No. 98,955
6 Claims. (Cl. 253-76)

This invention relates to an improved arrangement for reducing erosion in a turbo-machine wherein the motive fluid contains erosive matter, and particularly for protecting the highly stressed moving parts of the turbo machine. More specifically, the invention relates to the removal or control of erosive fly-ash in a coal-burning gas turbine with emphasis on protecting buckets of the early stages thereof.

It is well known that solid or liquid particles in the motive fluid of a turbine, such as a steam or gas turbine, can cause erosion, and that this erosion increases as an exponential function of the motive fluid velocity through the turbine. This is one of the major design problems which has delayed the advent of a successful coal-burning gas turbine. Since coal is cheaper, it would be preferable to the common gas turbine fuels, i.e., residual or distillate petroleum oils or natural gas. However, tests with experimental coal-burning gas turbines have indicated that concentrated erosion occurs at locations near the roots of the blade members. This is particularly serious in the highly-stressed rotating turbine buckets, and even more serious in the first-stage turbine bucket-wheel, which is subjected to a very high temperature of the motive fluid.

Accordingly, one object of the present invention is to remove or control erosive particles in the motive fluid of a turbo-machine.

A more specific object is to remove or control fly-ash or other suspended solids in a coal-burning gas turbine.

A still more specific object of the invention is to protect the buckets of the early stages in a coal-burning gas turbine, while keeping aerodynamic losses in the turbine to a minimum.

The subject matter of the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of practice, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawing in which:

FIG. 1 is an elevation drawing, in section, of the bladed portion of a coal-burning gas turbine, and

FIG. 2 is a schematic plan view of the first turbine stage.

Briefly stated, the invention is practiced by separating an early stage nozzle, such as the first-stage nozzle ring, axially from an early stage bucket, such as the first-stage bucket wheel, by more than a predetermined critical minimum spacing. The spacing is chosen so as to effect the outward movement of the solid particles by centrifugal force away from the critical root portion of the turbine bucket and to the outside diameter of the flow annulus where they may be removed.

In order to reduce aerodynamic losses engendered by the increased axial spacing and to further control erosion, the number of turbine stages is increased and at least one side wall of the flow annulus between first-stage nozzle and first-stage bucket may be arranged to rotate.

Referring now to FIG. 1 of the drawing, a portion of the turbine outer casing 1 forms the outside wall of an annular flow duct or flow annulus symmetrical with the turbine rotor axis (not shown) and commencing at the turbine inlet 2, where the flow direction is indicated by the arrow. The casing 1 serves as the means to support a number of circumferentially spaced, radially extending

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nozzle partitions designated 3, 4, 5, 6, 7 which serve to re-direct the motive fluid in each of the five turbine stages. Each of the nozzles 3-7 has vane portions 3a-7a disposed in the motive fluid path, and dovetailed base portions 3b-7b disposed in mating slots in casing 1, to hold the nozzles in place. The tips of nozzle partitions 4-6 do not include shrouds in this embodiment, but the radially innermost parts of nozzle partitions 3 and 7 include circumferentially extending shroud portions 3c, 7c respectively, to serve as the inner wall of the flow annulus. The foregoing comprise the stationary blade portions of the turbine.

Mounted on a rotating shaft (not shown) are a number of turbine wheels 8, upon which are disposed turbine buckets 9, 10, 11, 12, 13, serving to extract the energy from the motive fluid. A turbine bucket together with the nozzle partition ahead of it is called a "stage." Thus the first stage includes nozzle 3 and bucket 9; the second stage includes nozzle 4 and bucket 10 and so forth. The turbine buckets have vane portions 9a through 13a which are exposed to the motive fluid, and dovetailed base portions 9b through 13b mounted in mating slots on turbine wheels 8. Buckets 9-12 also include platform ledges 14 which extend axially toward one another and also abut circumferentially to form a rotating inner wall for the motive fluid flow path. Platform ledges 14 also substitute as sealing surfaces forming close clearances with the unshrouded stator partitions 4-6.

The tips of the buckets and nozzle partitions may also overlap beyond the roots of the vane portions of adjacent members, and the platforms of both nozzle partitions and buckets may be provided with erosion-resistant inserts 15 as set forth in my U.S. Patent 3,030,071 issued April 17, 1962, and assigned to the assignee of the present application. These inserts 15 serve as impingement surfaces for motive fluid and particles passing under the blade tips.

Separating the first-stage nozzle blade 3 and the first-stage turbine bucket 9 is an axial gap of a minimum distance "a," to be further specified. In order to provide a rotating inner side wall for the flow annulus across this axial gap, a number of "dummy" buckets 16 are provided. These are bucket bases with platform portions but no vane portions. The dummy buckets 16 abut circumferentially to provide a rotating inner side wall.

The outer casing wall 1 defines a contoured fly-ash extraction port 17 leading to an annular collecting chamber 18. Extraction port 17 as shown is a circumferential groove in the casing wall 1. A fly-ash removal pipe 19 connects with annular collecting chamber 18 and leads to a fly-ash collecting hopper or cyclone separator 20. The return line 21 is connected to a restricted inlet passageway 22 at a downstream or lower pressure location in the turbine, shown here as emptying into the flow path between bucket 9 and nozzle partition 4. The return line 21 serves to conserve the heat and pressure energy in the extracted motive fluid by returning it to the cycle.

The axial distance between the exit edge 3d of nozzle partition 3 and the downstream edge 17a of extraction port 17 is denoted by "a." Dimension "a" must be a minimum critical dimension in order for fly-ash particles leaving nozzle partition 3 at the radially innermost point thereof to pass out through extraction port 17 before hitting the edge 17a of the port. The path of a particle is symbolized by the dotted line 23, although it is understood that this is not a true path since the particle has axial, tangential and radial components of velocity all at the same time. The minimum axial spacing "a" is affected both by the inner and outer radii of the flow annulus taken from the rotor axis and by the tangential component of motion given to the fly-ash particle as it leaves the exit edge 3d of the nozzle partition 3. This is seen

more clearly by reference to FIG. 2 of the drawing, which is a schematic plan view showing two nozzle partitions 3 having trailing edges 3d and directing the gas toward two buckets 9. Axial spacing "a" is shown to extend between trailing edge 3d of the nozzle partitions and the downstream edge 17a of extraction 17.

The tangential component given to the fly-ash particles is determined by the angle α_1 which is the angle of the nozzle partition exit edge from the tangential direction measured at the radially innermost part of the nozzle partition vane exposed to the motive fluid. This minimum required axial spacing can be determined by the following formula:

$$\alpha = R_1 \tan \alpha_1 \sqrt{(R_o/R_1)^2 - 1}$$

where:

R_1 is the inner radius of the flow annulus measured from the rotor axis at the location of the nozzle partition trailing edge,

R_o is the outer radius of the flow annulus at the point where it is desired that the particles strike, and

α_1 is the nozzle partition exit angle measured from tangential taken at R_1 (see FIG. 2).

While the dimension "a" should not be less than the minimum axial spacing given by this expression, in actual machines, the distance may be made somewhat greater, depending on an analysis of particle density, particle size, and other variables.

The operation of the erosion protective arrangement may be described as follows. As the motive fluid is deflected into a tangential direction by nozzle partitions 3, both the gas and any entrained solid particles contained therein are subjected to a strong centrifugal field. The solid particles, being heavier, move both radially and circumferentially and, provided the spacing "a" is at least the minimum distance given by the formula above, the particles will exit through annular extraction port 17 into the annular collecting chamber 18, and from there will be blown through pipe 19 to the separator 20. The return line 21 will return the motive fluid to a restricted passageway 22, which is designed to control the amount of motive fluid being bled off through part 19. Of course, other means such as orifices or control valves may be substituted for the means to control the bleed flow, inasmuch as this should be held to as low a figure as possible. It is expected that a bleed flow through line 19 on the order of 3% of the total gas flow will effectively remove the fly-ash.

The spacing "a" introduces certain aerodynamic losses which are related to the boundary action of stationary walls on the axially and circumferentially moving gas stream. These losses may be greatly reduced by the provision of a specially rotating inner side wall formed by the "dummy" buckets 16. Since the inner side wall of the flow duct is turning in the same direction as the gas stream, the aerodynamic losses which would otherwise occur through friction from the boundary layer will be reduced by the use of such a rotating inner side wall.

These losses may be further reduced by increasing the number of stages in the turbine. Ordinarily, in a gas turbine designed to burn natural gases or residual oil, the first stage nozzle velocity is very high, perhaps on the order of 2000 ft./sec. when only two turbine stages are used. In a coal-burning gas turbine, on the other hand, a greater number of stages, five stages in the embodiment shown here, provide the dual function of reducing the gas velocity and also of reducing the overall aerodynamic losses due to gap "a." As to the first reason for increasing the number of stages, the erosion which takes place is an exponential function of the velocity of the gas relative to the blades. It has been determined that, for satisfactory blade life, these relative velocities must be kept below 900 ft./sec. and preferably below 500 ft./sec. By using a larger number of stages, the pressure drop per stage, hence the gas velocity, can be reduced. The second

reason for increasing the number of stages is that a certain extra percentage of aerodynamic loss is associated with each stage employing a spacing such as "a." The loss attributed to only the first stage spacing can be reduced insofar as the whole turbine is concerned by allotting a smaller portion of the total work to the first stage. Therefore, the total loss due to spacing "a" is progressively reduced for the overall turbine as stages are successively added. Thus, for most effective practice of the invention, it is anticipated that at least four stages are desirable, and preferably five or six stages for the optimum results.

Although the embodiment shown in FIG. 1 provides for actual removal of the fly-ash from the motive fluid, it is also within the purview of the invention to utilize the critical spacing "a," to control erosion by employing this critical spacing between a nozzle and its cooperating bucket wheel, without using extraction part 17 and collecting chamber 18. In this case, the minimum spacing "a" would be that required between the trailing edge 3d of the nozzle partition 3 and the leading edge of the adjacent bucket 9. By utilizing this minimum spacing between nozzle and bucket, any entrained solid particles will move to the outermost wall of the flow annulus before striking any part of the first-stage bucket. Thereafter the particles pass between the bucket tip and the casing through the clearance space 25, in which passage the particles will be re-accelerated axially due to the increased gas velocity occasioned by the pressure drop occurring across the bucket tips. The extent of erosion damage is minimized by impingement of these particles on the erosion-resistant inserts 15 in the second-stage nozzle base 4b projecting into the gas path. The hardened erosion shields 15 are described in more detail in the aforementioned U. S. Patent 3,030,071. A similar action occurs in the clearance spaces of the following stages which are similarly provided with erosion-resistant inserts. Thus by use of centrifuging spacing "a" without using extraction part 17 the erosive particles are concentrated at the outer sidewall where they will tend to remain throughout the entire turbine, and their erosion damage will be limited to an area near the bucket tips and primarily on the erosion shields 15, rather than in the more critical area of the highly stressed bucket roots.

It can be seen that the erosion protective arrangement described is primarily to protect the buckets of the early stages where the erosion problem is the most critical due to higher temperatures. The use of a rotating sidewall in the gap "a" and the use of at least four stages reduce the aerodynamic losses occasioned by the introduction of the axial spacing to an acceptable amount.

Therefore, the invention provides an effective arrangement for protecting the most highly stressed members in a coal-burning gas turbine against erosion by entrained flyash. The same principle is also obviously applicable to other turbo machines, such as steam turbines operating on saturated steam, in which the motive fluid contains solid or liquid particles which can be centrifuged and removed in the manner described herein. It is of course intended to cover in the appended claims all such modifications and applications as fall within the true spirit and scope of this invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a turbomachine utilizing fluid containing erosive particles and having a plurality of stages of alternating stationary and moving blades disposed in a flow annulus symmetrical with respect to the turbomachine axis, the combination of an outer annular casing portion, a circumferential row of radially extending stationary blades disposed in said casing portion, an adjacent circumferential row of radially extending moving blades, an inner sidewall for said flow annulus disposed between said stationary blade row and said moving blade row and rotating at the same speed as the moving blade row, and annular passage means defined between the casing por-

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tion and the tips of said moving blades, the entrance to said passage means being spaced from the trailing edges of the stationary blades by a minimum unobstructed axial distance

$$a = R_1 \tan \alpha_1 \sqrt{(R_0/R_1)^2 - 1}$$

where

R_1 is the inner radius of the flow annulus at the stationary blade row measured from the turbomachine axis,

R_0 is the outer radius of the flow annulus at the entrance to the passage means measured from the turbomachine axis, and

α_1 is the angle from tangential at the nozzle partition trailing edge measured at R_1 .

2. In a turbomachine utilizing motive fluid containing erosion-producing particles and having an outer casing portion enclosing a plurality of stages of alternating nozzle partitions and buckets, said casing, said nozzle partitions and said buckets defining portions of a flow annulus for the motive fluid, the combination of a stationary circumferential row of radially extending first-stage nozzle partitions, a moving circumferential row of radially extending first-stage turbine buckets spaced a substantial axial distance beyond said nozzle partitions, an inner circumferential sidewall extending between said first stage nozzle partitions and said first stage buckets and rotating at the same speed as the buckets, and extraction conduit means defined by the casing portion between the first-stage nozzle partitions and the first-stage buckets, and spaced beyond the nozzle partition trailing edges by a minimum unobstructed axial distance

$$a = R_1 \tan \alpha_1 \sqrt{(R_0/R_1)^2 - 1}$$

where

R_1 is the inner radius of the flow annulus at the first stage nozzle partition measured from the turbomachine axis

R_0 is the outer radius of the flow annulus at the extraction conduit means measured from the turbomachine axis, and

α_1 is the angle from tangential at the nozzle partition trailing edge, measured at R_1 .

3. In a coal-burning gas turbine, the combination of an outer casing defining the outer wall of a flow annulus, a plurality of axially-spaced circumferential rows of nozzle partitions disposed in said casing side wall and extending radially inward, a rotor turning within said casing having circumferentially extending portions defining an inner side wall for said flow annulus, a plurality of axially spaced circumferential rows of turbine buckets disposed on said rotor and extending radially outward and between said spaced nozzle partitions, the first row of nozzle partitions and the first row of turbine buckets being spaced apart by a substantial axial distance, an inner circumferential sidewall rotating at the same speed as the first bucket row and extending axially therefrom to the first nozzle partition row, said casing also defining an annular extraction conduit located between the first nozzle partition and the first turbine bucket rows, the entrance to said extraction conduit being axially spaced beyond the first nozzle partition trailing edges by a minimum distance

$$a = R_1 \tan \alpha_1 \sqrt{(R_0/R_1)^2 - 1}$$

where

R_1 is the inner radius of the flow annulus at the first stage nozzle, taken from the rotor axis,

R_0 is the outer radius of the flow annulus at the extraction conduit, taken from the rotor axis,

α_1 is the angle from tangential at the nozzle partition trailing edge taken at R_1 .

4. The combination according to claim 3, including means for bleeding motive fluid from said extraction conduit, removing solid particles, and returning the clean motive fluid to a lower pressure location in the motive fluid flow path in the turbine.

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5. In a coal-burning gas turbine having a plurality of stages of alternating nozzle partitions and buckets disposed in a flow annulus symmetrical with respect to the turbine axis, the combination of a circumferential row of radially extending first stage nozzle partitions, a casing portion defining a circumferential outer sidewall for a flow annulus, a moving circumferential row of radially extending first-stage turbine buckets having tips radially spaced from said casing portion, annular passage means defined between the casing portion and the bucket tips, the entrance to said passage means being axially spaced from the nozzle partition trailing edges by a minimum distance

$$a = R_1 \tan \alpha_1 \sqrt{(R_0/R_1)^2 - 1}$$

where

R_1 is the inner radius of the flow annulus at the first stage nozzle partition measured from the turbine axis,

R_0 is the outer radius of the flow annulus at the entrance to the passage means measured from the turbine axis,

α_1 is the angle from tangential at the nozzle partition trailing edge measured at R_1 ,

an inner circumferential sidewall extending between said first stage nozzle partitions and said first stage buckets and rotating at the same speed as the buckets, and an annular impingement wall extending radially inward from said casing portion on the other side of said passage means from said space "a," whereby fly ash particles leaving said nozzle partitions move to the outer sidewall before reaching said buckets and, after passing through said passage means, are decelerated by striking said annular impingement wall.

6. In a turbomachine utilizing fluid containing erosive particles and having a plurality of stages of alternating, stationary and moving blades disposed in a flow annulus symmetrical with respect to the turbomachine axis, the combination of an outer annular casing portion, a circumferential row of radially-extending stationary blades disposed in said casing portion, an axially spaced, co-operating circumferential row of radially extending moving blades, an inner circumferential sidewall extending axially between said moving blade row and said stationary blade row and rotating at the same speed as the moving blade row, and annular passage means by-passing said moving blades, the entrance to said passage means being located near the tips of said moving blades and being spaced from the trailing edges of the stationary blades by a minimum unobstructed axial distance

$$a = R_1 \tan \alpha_1 \sqrt{(R_0/R_1)^2 - 1}$$

where

R_1 is the inner radius of the flow annulus at the stationary blade row measured from the turbomachine axis,

R_0 is the outer radius of the flow annulus at the entrance to the passage means measured from the turbomachine axis, and

α_1 is the angle from tangential at the nozzle partition trailing edge measured at R_1 .

References Cited in the file of this patent

UNITED STATES PATENTS

1,834,452	Frey	Dec. 1, 1931
1,944,520	Meyer	Jan. 23, 1934
2,288,734	Noack	July 7, 1942
2,636,666	Lombard	Apr. 28, 1953
2,802,618	Prachar	Aug. 13, 1957
2,879,936	Faught	Mar. 31, 1959

FOREIGN PATENTS

547,332	Germany	Mar. 10, 1932
446,476	Italy	Mar. 18, 1949
1,115,125	France	Apr. 19, 1956