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(54) **Control of low volumetric flow instabilities in steam turbines**

(57) Configuration (10) of the last stage of a steam turbine where rotor blades (2) rotate encircled by a vane carrier (1), such that a plurality of passages (20) are located in the vane carrier (1), such that a fluid is blown through these passages (20) forming a flow that impinges onto the rotor blades (2), the number of passages (20), the location of the passages (20) in the vane carrier (1) and the velocity of the flow impinging onto the rotor blades (2), being calculated in such a way that rotating flow instabilities in the rotor blades (2) when the steam turbine operates at low volumetric flow conditions are avoided.

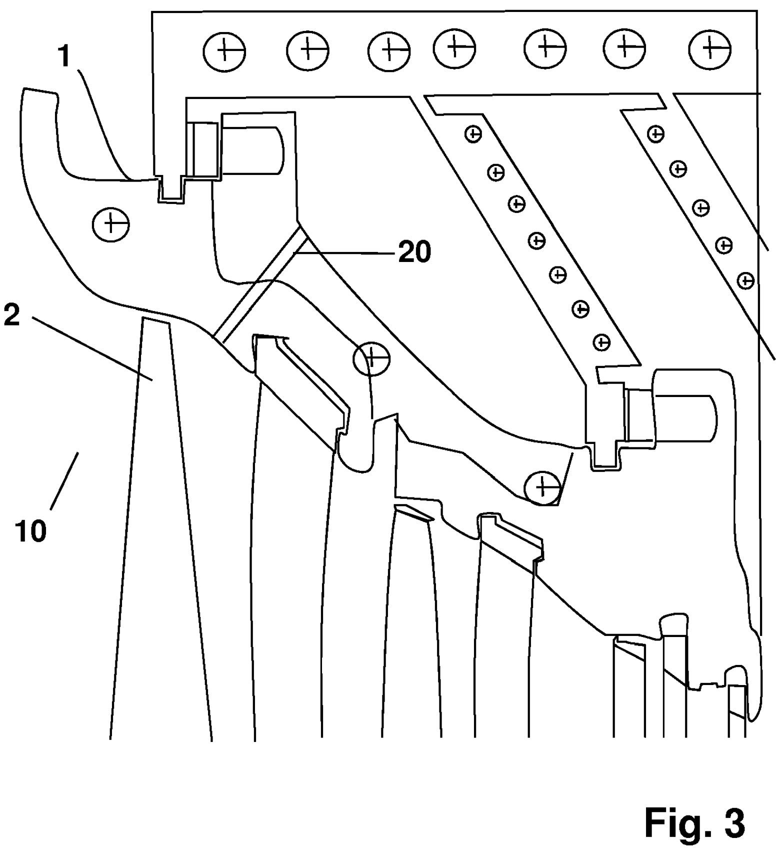

Fig. 3

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a configuration of the last stage in a steam turbine for controlling rotating flow instabilities in the last stage rotor blades when the steam turbine operates at low volumetric flow conditions, particularly during starting and low load conditions.

BACKGROUND

[0002] Stalling is a known phenomenon based on the sudden decrease of the load exerted onto a profile subjected to a flow: in steam turbines, the stalling phenomenon induces rotating flow instabilities in the rotor blades, particularly in the last stage rotor blades.

[0003] In steam turbines, during starting and low load conditions (up to around 10% of the design mass flow), the flow structure is very disorderly, particularly in the low pressure stage of the steam turbine: this flow is centrifuged radially outwards in the rotor blades, the flow being centrifuged radially inwards in the stator blades. At low load conditions there is high flow incidence onto the last stage rotor blades, which can cause flow separation from the rotor blades surface and flow instabilities, these instabilities are commonly found to rotate at about one half of the blade rotational speed. At this point the flow field also contains large toroidal vortex structures are set up. These rotating instabilities can couple with the natural frequency of the rotor blades and produce undesirable vibration effects.

[0004] Some solutions known in the prior art minimize this problem by removing the last stage low pressure channel, which is replaced by a newly designed part, frequently comprising a perforated plate. However, this results in a great loss of efficiency in the steam turbine, also being very costly. Besides, it is possible that the rotating flow instabilities move upstream and makes that other stages in the steam turbine fail.

[0005] The invention is oriented towards solving these problems.

SUMMARY OF THE INVENTION

[0006] The present invention relates to a configuration for controlling flow instabilities in steam turbines when they operate at low volumetric conditions, particularly during starting and low load conditions. The configuration of the invention comprises a plurality of passages located in the last stage vane carrier of the low pressure stage of the steam turbine, these passages being located at specific positions at the vane carrier: through these passages, a fluid is blown onto the rotating blades to counteract rotating flow instabilities in them. The number of passages and their specific positions are defined in such a way that the fluid blown is directed towards the rotor blades and preventing the excitation.

[0007] According to one embodiment of the invention, the passages are shaped circumferentially in order to increase the circumferential coverage of each passage.

[0008] The fluid blown through the passages into the rotor blades is such that the swirl injection angle incident on the rotor blades forms an angle from zero to -90 degrees. The positive angle being taken in the direction of the turbine rotor rotation, with zero degrees being axial, wherein in the axial/radial plane the jet is directed downwards from the outer flow boundary.

[0009] With the configuration of the invention, a near complete elimination of the rotor blade vibration is achieved.

BRIEF DESCRIPTION OF DRAWINGS

[0010] The foregoing objects and many of the attendant advantages of this invention will become more readily appreciated as the same becomes better understood by reference to the following detailed description when taken in conjunction with the accompanying drawings, wherein:

Figure 1 shows the characteristics of low flow in a steam turbine. Radial movements of the through flow can be seen together with the recirculation zones created;

Figure 2 shows an embodiment of the invention where the passages are shaped in the circumferential direction to increase the flow coverage for each passage provided;

Figure 3 shows schematically the configuration of the invention for controlling flow instabilities in the last stage rotor blades of a steam turbine when the turbine operates at low volumetric conditions;

Figures 4a,b,c shows the influence of injection swirl angle on Volumetric flow versus fractional Speed and Vibration amplitude; and

Figure 5 shows the influence of blowing mass flow on dynamic blade stress.

DETAILED DESCRIPTION OF THE INVENTION

[0011] The present invention relates to a configuration 10 for controlling flow instabilities in the last stage rotor blades 2 of a steam turbine when the turbine operates at low volumetric conditions, particularly during starting and low load conditions. The configuration 10 is such that a plurality of passages 20 are located in the vane carrier 1 of the last stage of the steam turbine, these passages 20 being located at specific positions at the circumference of the vane carrier 1. Through these passages 20, a fluid is blown onto the rotor blades 2. The number of passages 20 and their specific positions are defined in such a way that the fluid blown through the passages 20 is directed towards the rotor blades 2 avoiding rotating stability problems in these last stage rotor blades 2 that produce undesired vibration effects on them.

[0012] Figure 1 shows the flow pattern in the last stage low pressure vane carrier 1 during starting and low load conditions (up to around 10% of the design mass flow), showing that the flow structure is very disorderly. The through flow in the vane carrier 1 adopts a wavy shape, as shown in Figure 1, existing large toroidal vortex structures 30: the last stage low pressure vane carrier 1 actually acts as a radial pump and there is net energy input to the stage. According to the known prior art, a solution is to use water sprays injected in the exhaust diffuser to cool the exhaust casing vane carrier walls and last stage blades, but this solution has not been found to be reliable.

[0013] The purpose of the configuration 10 of the invention is to design the passages 20 to eliminate the rotating flow instabilities in the last stage rotor blades 2 during starting and low load conditions of the steam turbine.

[0014] The positions of the passages 20 upstream of the last stage rotor blade 2 is such that the injection flow is directed through the last stage vane carrier 1 to approximately 80% last stage blade height, as measured from the blade platform to the tip, so as to blow into the torodial vortex 30 typically formed upstream of the rotor blade 2 tip region.

[0015] From the series of Figs. 4a, 4b and 4c shows a series of tests that demonstrate the surprising effect that a negative injection angle results in a more stable and steady separated flow, decoupled from resonance can be seen. The tests were carried out in a one third scale model low pressure steam turbine over a range of mass flow rates and condenser pressure. During the tests measurement were made of last stage blade stress using a strain gauge located on the surface of the last stage blade. Results of these measurements are shown as lines representation vibrational amplitude in Figs. 4a, 4b and 4c.

[0016] An additional dynamic pressure sensor, acting as a microphone, was additional located in the flow to detect the formation of the rotating events that can give rise to blade vibration. From the pressure signal it was possible to determine frequency, which is transformable into fractional speed, and represent this as spheres in Figs 4a, 4b and 4c. The amplitude from the pressure sensor was then used in Figs. 4a, 4b and 4c to define the size of the grey spheres on each of the graphs.

[0017] Plots were then produced of fractional speed and vibrational amplitude versus volumetric flow for each of the cases of +60 degree injection as shown in Fig 4a no injection as shown in Fig. 4b, and -60 degree injection as shown in Fig. 4c, wherein volumetric flow is defined as the average axial flow velocity leaving the last stage divided by the blade root speed.

[0018] In each case, measured high vibration amplitude events were found to coincide with higher dynamic pressure amplitude and loss of its frequency scatter. With an injection at +60 degrees appeared to exacerbate vibrational amplitude, as seen in Fig. 4a when compared with the no injection case shown in Fig. 4b. With an injection angle of -60 it was possible to eliminate blade vibration, as can been seen in Fig. 4c. As further shown in Fig. 5, a negative injection rate has a positive effect on reducing relative dynamic stress even at very shallow injection angles.

[0019] According to an embodiment, the fluid injected from the passages 20, which preferably is steam, is such that the injection angle incident on the rotor blades 2 forms an angle from zero to -90 degrees, the negative angle being taken in the direction counter to the turbine rotor rotation. According to a further embodiment of the invention, the preferred injection angle range is -45 to -75 degrees, the most preferred injection angle being -60 degrees. According to still a further embodiment of the invention. The flow injected from the passages 20 is up to 10% of the mainstream flow.

[0020] The number of passages 20 relative to the number of rotor blades 2 is set to provide sufficient stabilization of the rotating events. In the case of the test results given, 12 passages were used. Other embodiments of this invention may use a different number of passages to obtain sufficient stabilization.

[0021] In an embodiment of this invention the passages are equally spaced around the circumference. In an alternative embodiment the passages are unevenly spaced around the circumference for enhanced performance or for practical considerations.

[0022] Together with the injection angle the velocity of the fluid blown onto the rotor blades 2 is also important.

[0023] Therefore, the following parameters influence the performance of the configuration 10 of the invention maintaining the trajectory length of the fluid blown from the passages 20 as small as possible; maintaining the velocity of the fluid injected as high as possible; and maximizing the circumferential extent of the passages 20 in the vane carrier 1.

[0024] It is difficult to weight the above-cited parameters and, therefore, a different optimum absolute injection angle exists and has to be calculated for each specific case.

[0025] According to one embodiment of the invention, the passages 20 are circumferentially shaped to increase the circumferential coverage in the vane carrier 1 as shown in Fig. 2.

[0026] With the configuration 10 of the invention, a major minimization of the rotor blades 2 vibration and of their critical resonance is achieved. Moreover, the use of passages 20 to control rotating flow instabilities constitutes a way of controlling the flow instabilities rotating problem and does not lead to a loss in the efficiency at design full-load conditions.

[0027] Although the present invention has been fully described in connection with preferred embodiments, it is evident that modifications may be introduced within the scope thereof, not considering this as limited by these embodiments, but by the contents of the following claims.

1	Last stage vane carrier
2	Rotor blades
10	Configuration for controlling flow instabilities
20	Passages
30	Toroidal vortex in the vane carrier

Claims

1. Configuration (10) of a last stage of a steam turbine where rotor blades (2) rotate encircled by a vane carrier (1), **characterized in that** a plurality of passages (20) are located in the vane carrier (1), such that a fluid is blown through these passages (20) upstream of the rotor blades (2) and arranged to form a flow that impinges onto the rotor blades (2) with an injection angle of between zero to -90 degrees against the rotation of the rotor blades (2) such that rotating flow instabilities in the rotor blades (2) when the steam turbine operates at low volumetric flow conditions are reduced.

2. Configuration (10) according to claim 1, wherein the passages are configured and arranged to blow fluid towards a point that is approximately 80% of a height of the last stage rotor blade (2) taken from a base to a tip of the rotor blade (2).

3. Configuration (10) according to claim 1, wherein the plurality of passages (20) are circumferentially uniformly spaced in the vane carrier (1).

4. Configuration (10) according to claim 3, wherein the plurality of passages (20) circumferentially uniformly spaced in the vane carrier (1) number eight.

5. Configuration (10) according to claim 3, wherein the plurality of passages (20) circumferentially uniformly spaced in the vane carrier (1) number twelve.

6. Configuration (10) according to claim 1, wherein the passages (20) are circumferentially shaped in such a way that a circumferential coverage in the vane carrier (1) is increased.

7. Configuration (10) according to claim 1, wherein the injection angle is in a range from -45 to -75 degrees.

8. Configuration (10) according to claim 1, wherein the injection angle is about -60 degrees.

9. Configuration (10) according to claim 1 wherein in that the flow injected through the passages (20) is up to 10% of the mainstream flow circulating through the rotor blades (2) and the vane carrier (1).

10. Configuration (10) according to claim 1 wherein in that the flow injected through the passages (20) is approximately 10% of the mainstream flow circulating through the rotor blades (2) and the vane carrier (1).

11. Configuration (10) according to claim 1, wherein the fluid blown through the passages (20) is steam.

12. A steam turbine comprising a last stage configuration (10) according to any of claims 1 to 10.

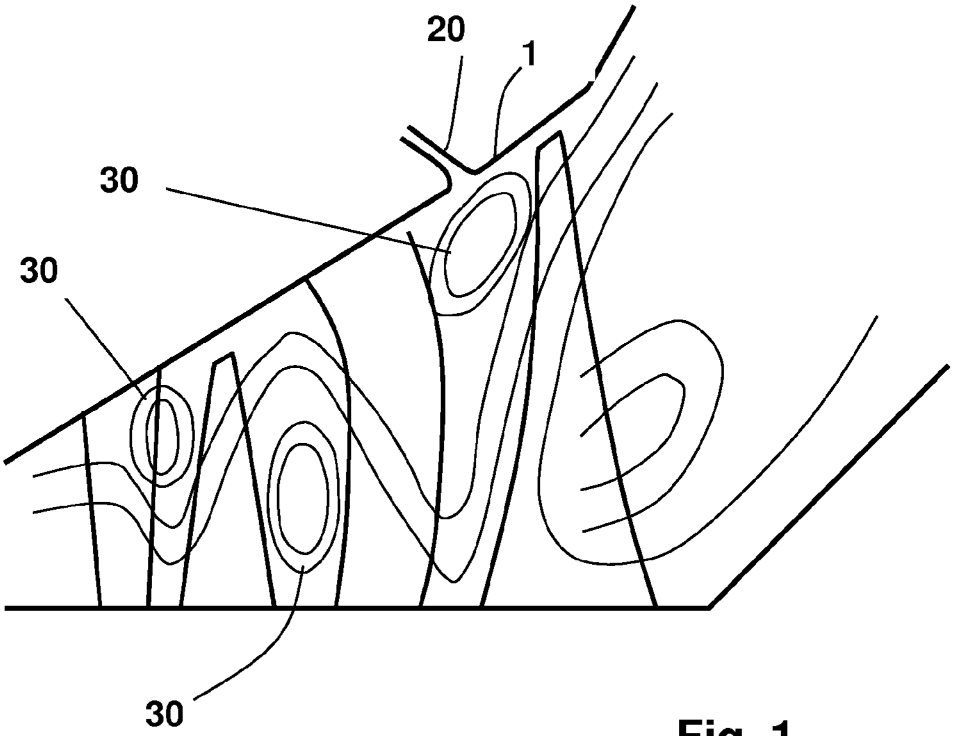

Fig. 1

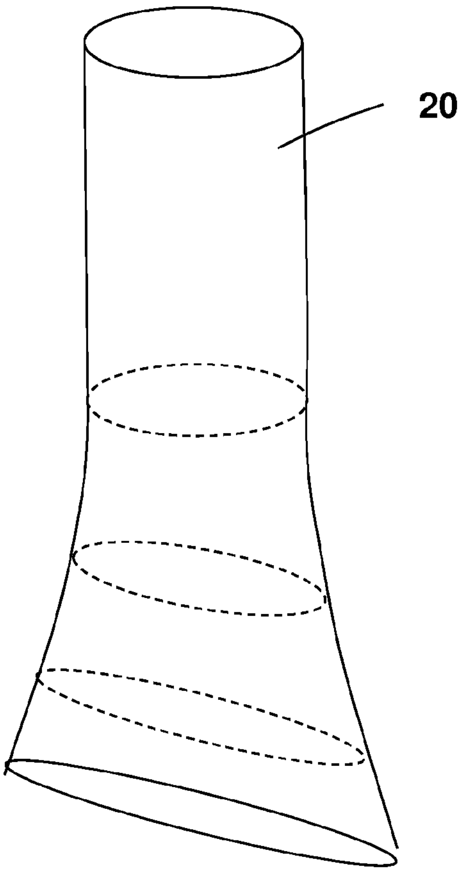

Fig. 2

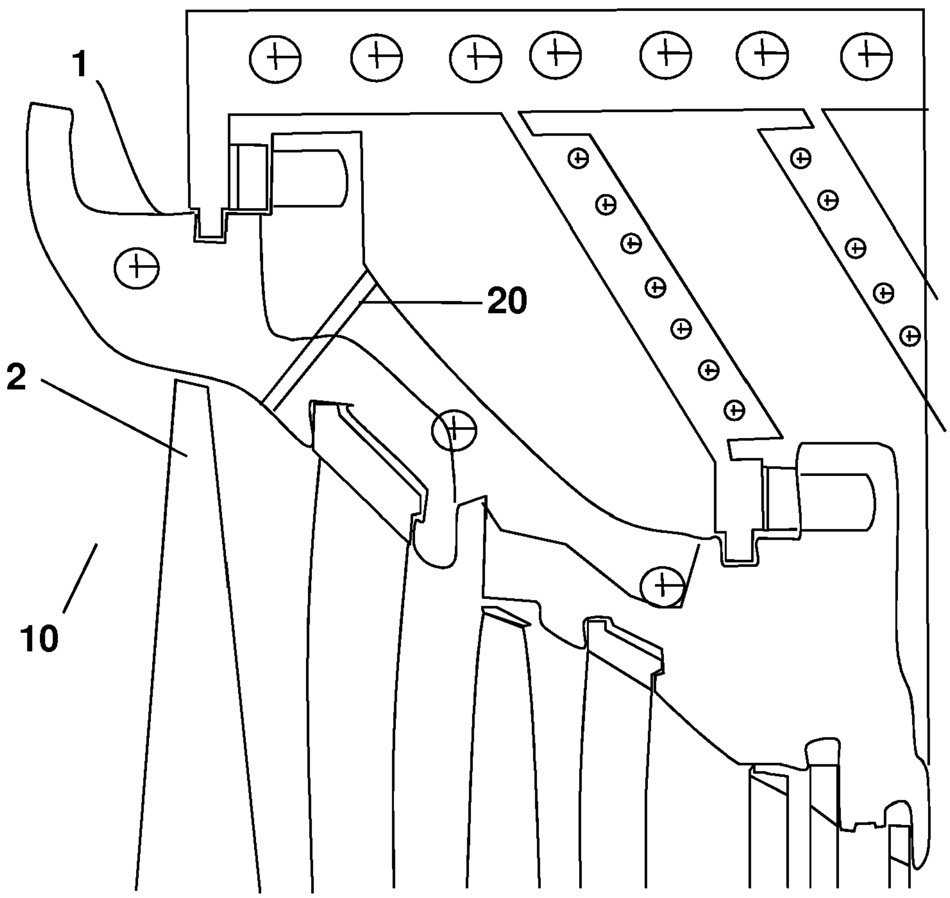

Fig. 3

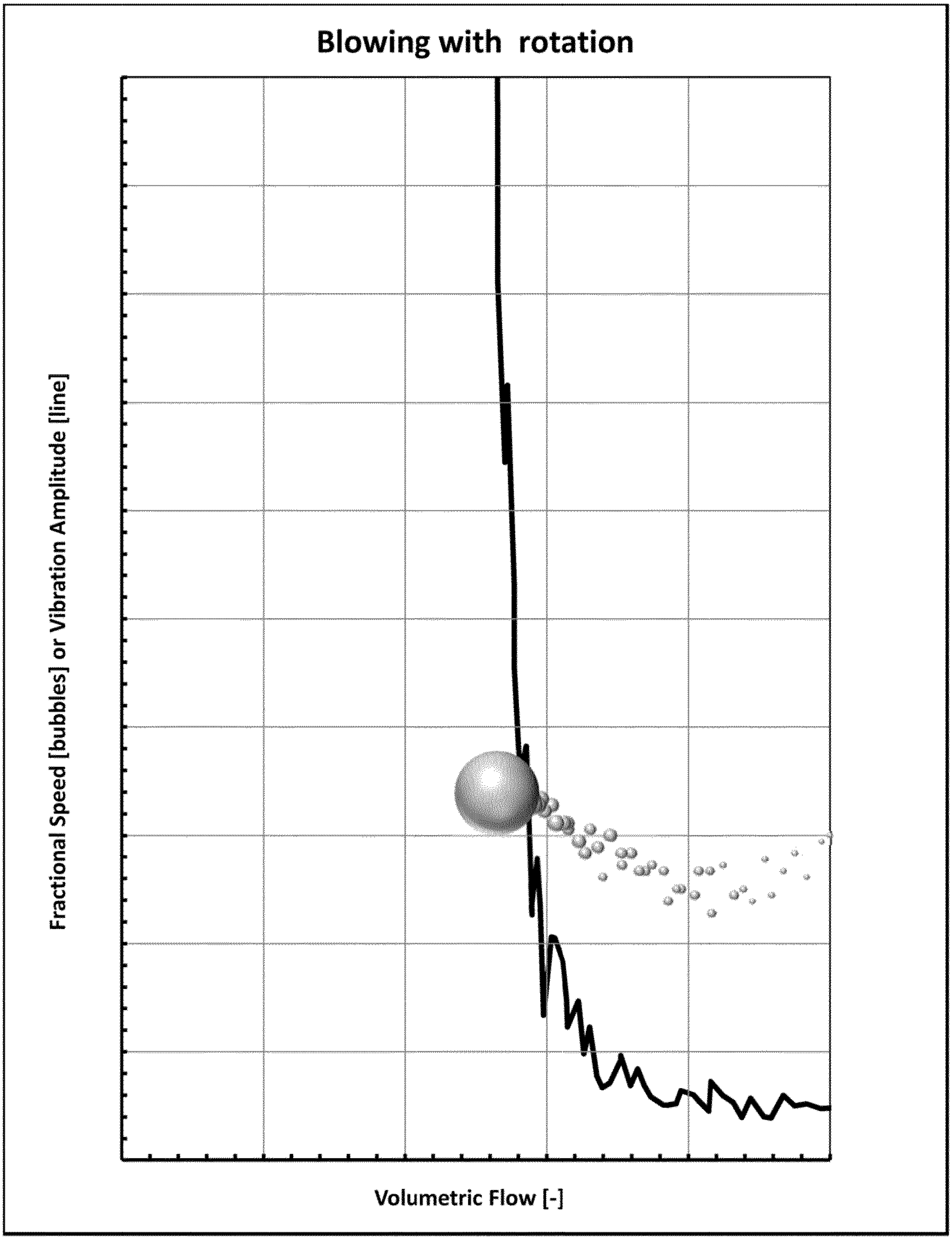
Blowing with rotation
Fractional Speed [bubbles] or Vibration Amplitude [line]
Volumetric Flow [-]

Fig. 4a

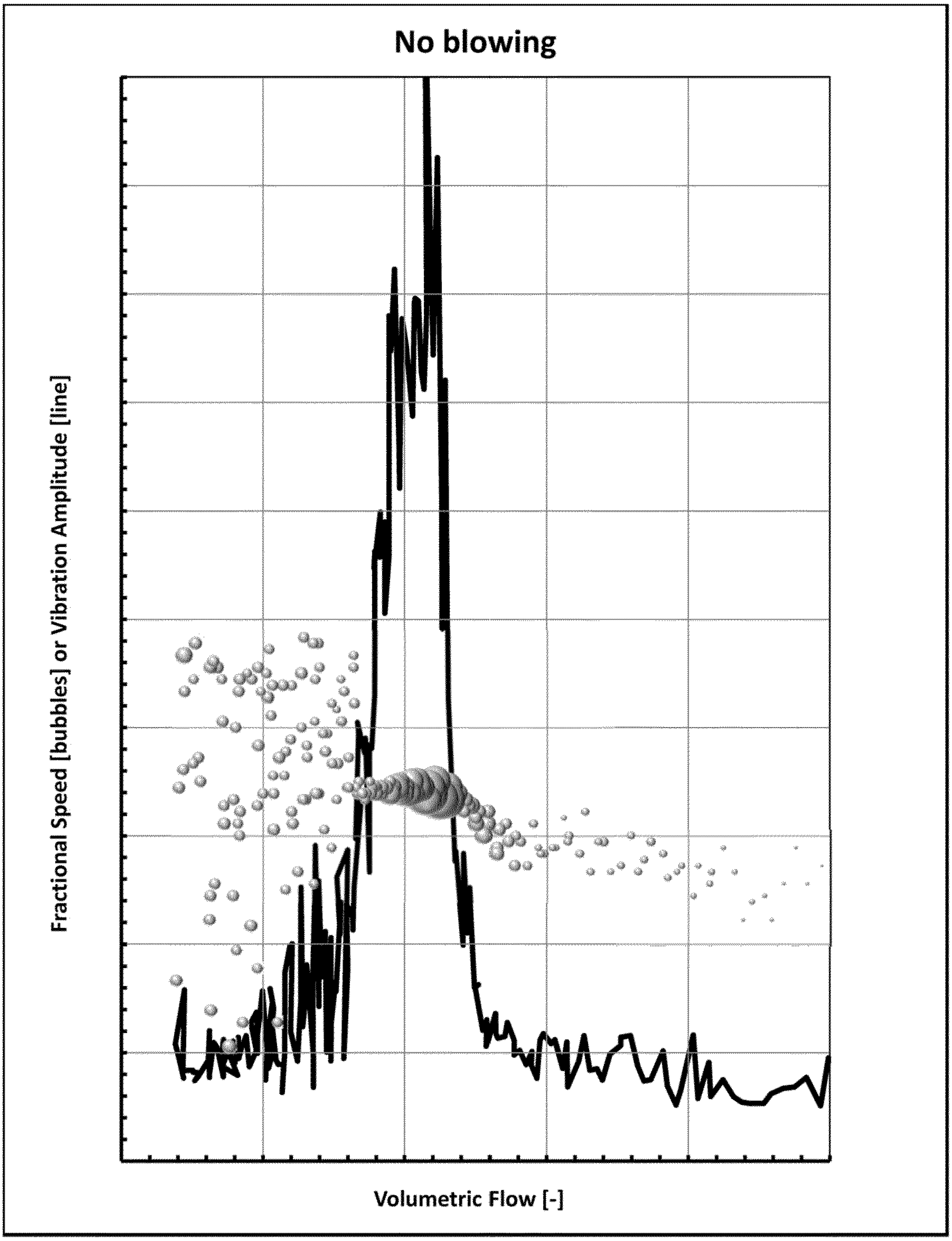
No blowing
Fractional Speed [bubbles] or Vibration Amplitude [line]
Volumetric Flow [-]

Fig. 4b

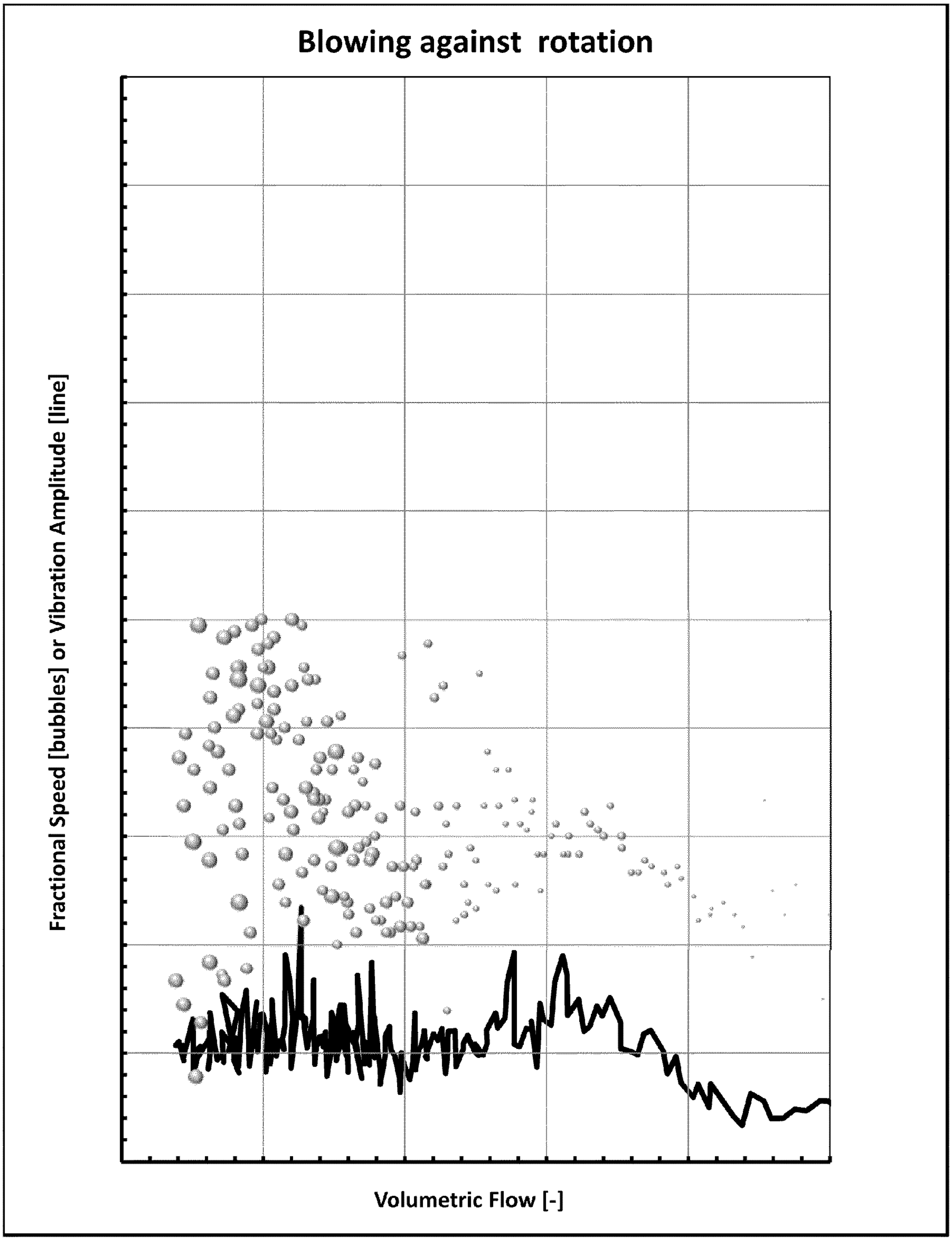
Blowing against rotation
Fractional Speed [bubbles] or Vibration Amplitude [line]
Volumetric Flow [-]

Fig. 4c

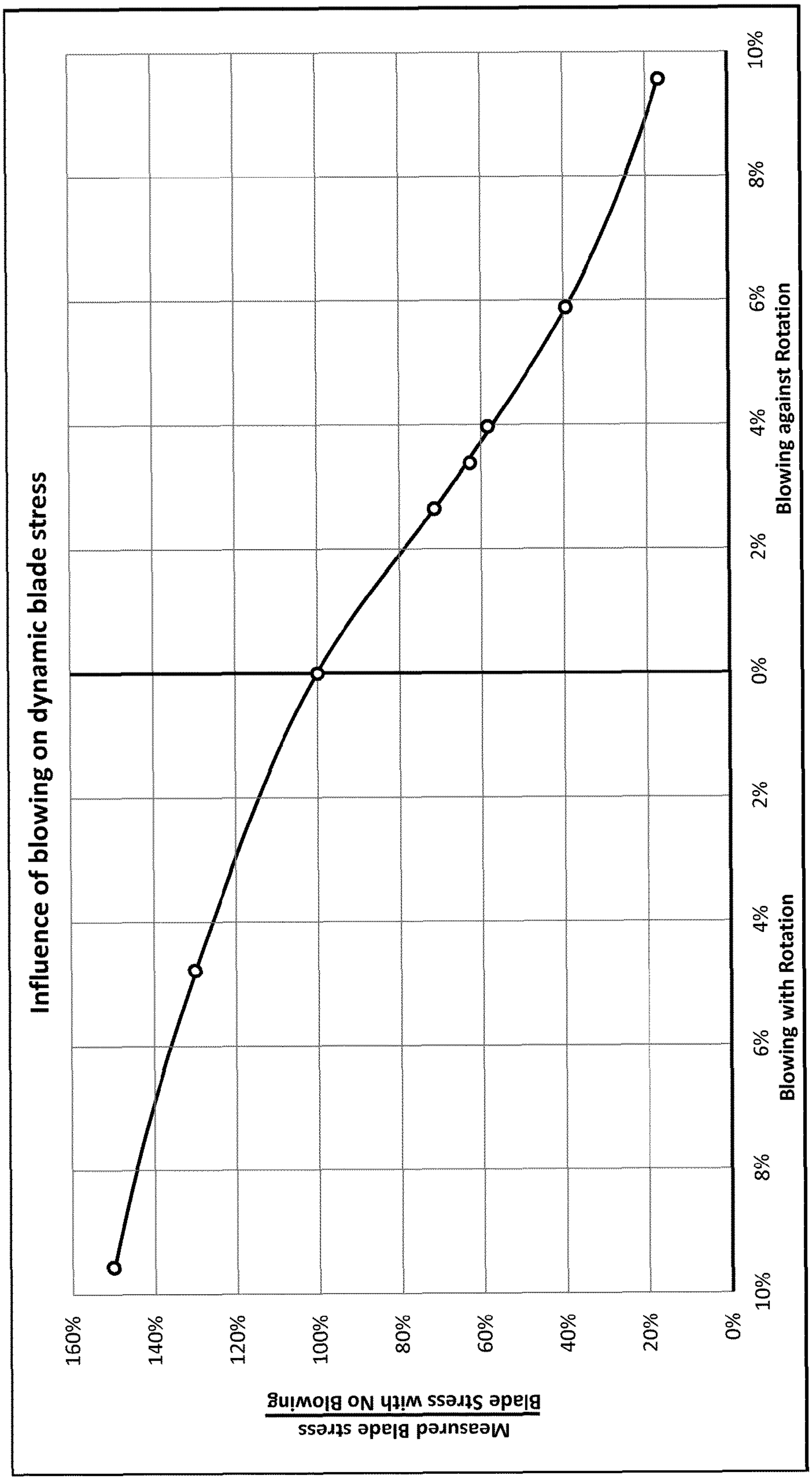
Influence of blowing on dynamic blade stress
Measured Blade stress
Blade Stress with No Blowing
160%
140%
120%
100%
80%
60%
40%
20%
0%
10%
8%
6%
4%
2%
0%
2%
4%
6%
8%
10%
Blowing with Rotation
Blowing against Rotation

Fig. 5