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APPARATUS FOR NON-DESTRUCTIVE INSPECTION OF CANTILEVERED MEMBERS

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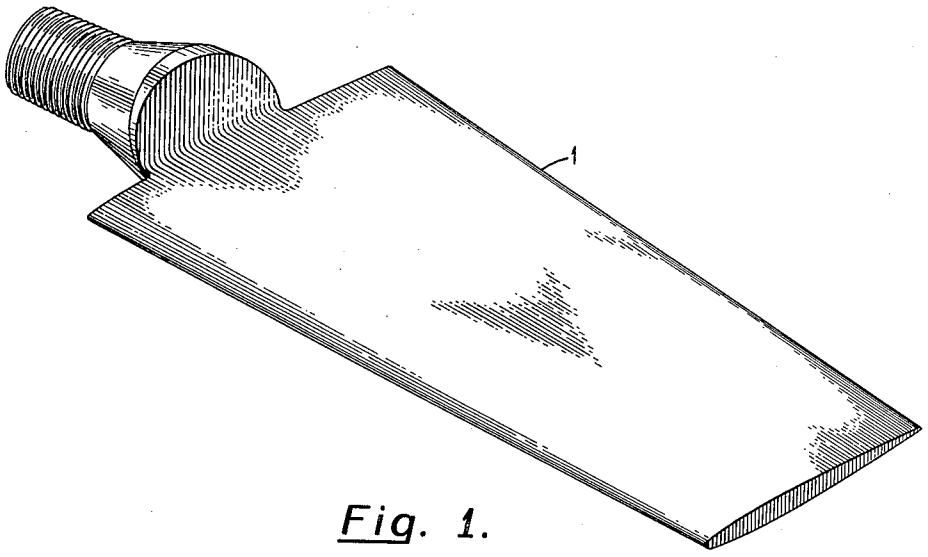



Fig. 1.

INVENTORS.
Ernest R. Taylor
Charles H. Mahoney
Clarence R. Lay

BY Roland A. Anderson
ATTORNEY

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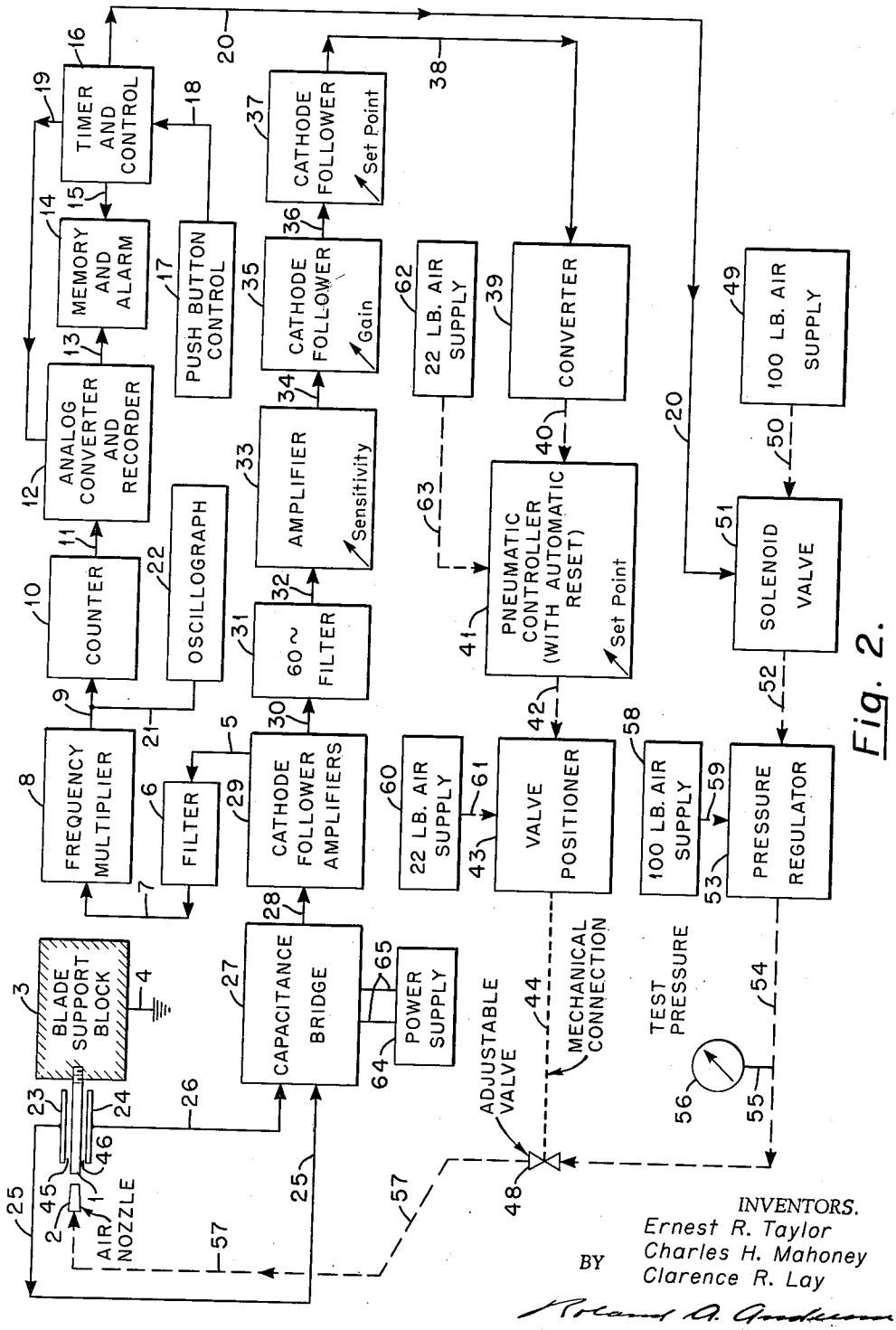



Fig. 2.

INVENTORS.
Ernest R. Taylor
Charles H. Mahoney
Clarence R. Lay

BY

ATTORNEY

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# APPARATUS FOR NON-DESTRUCTIVE INSPECTION OF CANTILEVERED MEMBERS

Ernest R. Taylor, Knoxville, Charles H. Mahoney, Oak Ridge, and Clarence R. Lay, Kingston, Tenn., assignors to the United States of America as represented by the United States Atomic Energy Commission

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1 Claim. (Cl. 73—67.3)

This invention relates to apparatus for inspection of articles which in their normal service use are supported in cantilever fashion. One example of such articles are compressor blades of the type which are installed in axial flow compressors. It is eminently desirable to conduct a non-destructive inspection of such blades befores their installation or use for defects that will cause premature structural failure of the blades when in use. When a compressor blade breaks off when in use, it will cause considerable damage to other blades within the compressor and will effect breakage of many blades before the compressor is shut down. From the standpoint of economy, it is desirable that such shut-downs be kept at a minimum, and this can only be accomplished by insuring that the blades are structurally sound before installation or use.

Compressor blades may be formed by die casting, forging or other means from aluminum alloys or other metals. Die cast aluminum alloy blades, like other die cast shapes, are characterized by some degree of shrinkage cavitations, gas porosity, enfoliations, and surface folds. In some instances, the distribution, shape, and size of these irregularities are such that the blade is weakened and will fail prematurely under normal service conditions. Usually such failure occurs in the so-called fillet region, which is the region where the greatest stress concentration occurs in service. A pressing need existed prior to our invention for a rapid and relatively inexpensive method for determining, with a high degree of reliability, which compressor blades are likely to prematurely fail in the fillet region if operated under normal service conditions. Conventional methods of blade inspection, such as radiography, fluoroscopy, microscopy, and dye penetrant techniques have been employed, but none have resulted in dependable separation of sound from defective blades because of inability with these methods to discriminate between apparent defects and those contributing to shortened blade life. In addition, these conventional methods of inspection are time consuming, and where it is desired to inspect a large number of blades, the method set forth in our invention is much more rapid as compared with the conventional methods.

With a knowledge of the shortcoming of prior methods for inspection of blades, it is a primary object of this invention to provide apparatus for non-destructive inspection of compressor blades and the like under service-like conditions.

It is another object of this invention to provide apparatus for inspection of compressor blades and the like which is reliable, rapid and relatively inexpensive.

It still another object of this invention to provide apparatus for inspecting compressor blades and the like wherein a blade is vibrated at its natural frequency and excessive decay or an erratic shifting in the frequency of vibration is indicative of a faulty blade.

These and other objects and advantages of this invention will be apparent from a consideration of the following detailed specification and the accompanying drawings wherein:

FIG. 1 is a showing of a typical compressor blade, and

FIG. 2 is a schematic diagram showing means for vibrating a blade at a constant amplitude of vibration and a frequency-responsive system for detecting excessive decay or



an erratic shift in frequency of vibration as indicative of a faulty blade.

The above objects have been accomplished in the present invention by mounting a compressor blade under service-like conditions, vibrating the blade with a regulated source of air under pressure, maintaining the amplitude of vibration of the blade at its natural frequency, measuring the frequency of vibration of the blade, and indicating an excessive decay or erratic shifting in said measured frequency as identification of a faulty blade.

Refer now to the drawings which illustrate one embodiment in which the principles of this invention may be carried out.

FIG. 1 shows a typical compressor blade. If such a blade is defective, it will usually fail in the fillet region, as it is in this region that the maximum stress concentration occurs in the blade when a vibratory load is applied.

In FIG. 2, a typical blade 1 is mounted in a support block 3 in a manner simulating service conditions. Preferably, the blade is mounted substantially in axial alignment with an air nozzle 2, and the tip of the blade is separated from the nozzle by a minimum clearance on the order of a few thousandths of an inch. Pressurized air is fed to the nozzle 2 from a source of air supply 49, through a connecting tube 50, solenoid valve 51, tube 52, pressure regulator 53, tube 54, regulating valve 48, and tube 57. A source of air supply 58 is connected by a line 59 to the pressure regulator 53. The blade 1 is grounded through mounting block 3 and by a lead 4 connected to ground. The valve 48 can be adjusted manually to maintain a selected amplitude of vibration of blade 1 under inspection, or it can be automatically adjusted by means which will be described hereinafter to regulate the flow of air to nozzle 2 to maintain the selected amplitude of vibration of the blade 1.

While the shape of the nozzle 2 is not highly critical, one suitable type is formed with a rectangular outlet portion, the inside major dimension being one-third the blade tip chord length, and the inside minor dimension being equivalent to the major thickness of the blade at the blade tip. With this arrangement, assuming that the compressor blade is tightly seated in the support block 3, the blade can be excited in the first bending mode by adjusting the mass flow of air and, if necessary, by carefully adjusting the nozzle in a plane perpendicular to the axis of the blade. When the nozzle has been properly positioned, the unit mass flow of air along the two major faces of the blade are substantially the same. Assuming proper adjustment of the mass flows, the typical blade will vibrate at its natural frequency, the amount of deflection of the blade being essentially constant for given flow conditions. The amplitude of vibration can be adjusted either manually or automatically by controlling the rate of air flow to the nozzle as discussed hereinafter to insure exact duplication of test for blades of the same size and type.

A meter 56 is connected to the pressure line 54 by a tube 55 and it gives a ready indication of the test pressure.

The mass of the block 3 and supporting base, not shown, is made large relative to that of the blade 1 in order to avoid interfering or resonant vibrations. The blade 1 is flanked on opposite sides by plate electrodes 23 and 24 which are contoured to match the blade 1. Means, not shown, are provided for adjusting the spacing between the blade 1 and electrodes 23 and 24 so that they define two matched condensers 45 and 46, the blade 1 serving as a plate common to both. The two condensers 45 and 46 are incorporated in a conventional capacitance bridge 27. Plates 23 and 24 of the condensers 45 and 46 are connected to bridge 27 by leads 25 and 26, respectively. A D.C. power supply 64 is connected to bridge 27

by leads 65. The bridge 27 is at balance when the blade 1 is at rest.

In a normal operation, vibration of the blade 1 by a jet of air issuing from nozzle 2 unbalances the bridge 27, generating an alternating output signal whose frequency is equal to the frequency of vibration and whose amplitude is proportional to the amplitude of vibration of the blade 1. The output from the bridge 27 is fed by a line 28 into a two-stage cathode follower amplifier 29. The output of one stage of the cathode follower amplifier is fed by a line 5 into a multi-selector by-pass filter circuit 6, whose output is fed by line 7 into a frequency multiplier 8. The frequency multiplier 8 is used to multiply the frequency signal by 1, 2, or 4, depending on the sensitivity required to measure accurately a change in frequency of the sample under test. Normally the lower frequency samples require the higher multiplications. The signals from the frequency multiplier are transmitted by a line 9 to an electronic decade frequency counter 10, which counts the frequency of vibration in cycles per second or a multiple thereof, depending on the setting of the frequency multiplier. The output signal from the counter 10 is fed by a line 11 to an analog converter and recorder 12 which in turn is connected by a line 13 to a memory and alarm circuit 14. A timer and control mechanism 16 is connected by a line 15 to the memory and alarm circuit 14, connected by a line 19 to the analog converter and recorder 12, and connected by a line 20 to the solenoid valve 51 in the pressure line to nozzle 2. A push button control circuitry 17 is connected by line 18 to the timer and control mechanism 16.

The memory and alarm circuit 14, in conjunction with the analog converter and recorder 12, stores and records the initial frequency reading obtained at the end of a 25-second period. The timing sequence for the test cycle does not start for about 25 seconds after the start button in unit 17 has been pushed, because time is needed for the sample to reach the desired amplitude and 10 seconds is required by the decade counter 10 to automatically reset, after the desired amplitude has been reached, before introducing a signal to the memory circuit 14. The signal generated by the vibrating sample is picked up by and transmitted through the capacitance plates 23 and 24. The capacitance plates together with the balancing bridge 27 supply the basic signal that is used to measure the frequency and control the amplitude of vibration of the sample. At the end of a timed inspection cycle, the final frequency reading is compared to the original frequency stored in the memory circuit and is indicated on the recorder. The timer and control circuit 16 automatically stops the sequence of the test after a predetermined time. If the frequency of the sample has dropped below a value preset on the alarm circuit 14, an alarm light will indicate that the sample is defective. The timing circuit 16 energizes the solenoid valve 51, which stops the air flow to nozzle 2 at the conclusion of the test sequence.

We have selected a test period of approximately two minutes as the maximum period because we have found that if a blade is defective, it will be detected by a decay in frequency during this period. Also, it is desirable from the standpoint of production economies, when it is desired to test a large quantity of blades, to keep the test period at a minimum commensurate with the requirements for an adequate test. In a typical inspection test of die cast blades, the decay in frequency that is indicative of a defective blade, may range up to 2.0 cycles per second, dependent on blade design and vibratory characteristics. This decay of up to 2.0 cycles per second is in excess of a decay that is caused by a hysteretic effect, which is small and may range up to one-half of one percent of the measured frequency.

The criteria used in inspecting the blades by the frequency decay method require that a sound blade will withstand the vibratory load, without evidence of decay in its resonant frequency more than that due to hysteresis, for a period that is at least 6 times longer (dependent on blade type) than the period that can be withstood by an unsound blade. The duration of the test is that time required for an unsound blade of a given type to exhibit a distinct, progressive decay or an erratic shift in resonant frequency. These criteria are established for each type by testing to failure both sound and cracked blades. The decay ascribed to hysteresis can be established for each blade type by testing both sound and cracked blades at selected test amplitudes and times. This allowable decay is inherent in the castings and results from hysteretic loss. Its numerical value varies with configuration, and is influenced by metallurgical factors related to the uniformity of the die castings. Frequency decay in excess of this limit is caused by defects such as cracks or excessive porosity.

The output of frequency multiplier 8 is connected by lines 9 and 21 to an oscillograph 22 for monitoring the signal received by the decade counter 10 to aid in the proper setting of the filter 6.

As set forth above, the flow of air to nozzle 2 can be regulated either manually or automatically. When manual control is desired, the cathode follower amplifier 29 is provided with only one stage which is coupled to the frequency measuring circuitry as set forth above, and the automatic amplitude control system, described below, is not employed. Under manual operation, the valve 48 is regulated manually to maintain a constant amplitude of vibration of the blade 1 under inspection.

The flow of air to nozzle 2 can be regulated automatically and the apparatus for accomplishing this will now be described. As shown in FIG. 2, the output signal from the second stage of the cathode follower amplifier 29 is connected by a line 30 across a standard filter 31 designated to reject any sixty-cycle pick-up. The output from the filter 31 is fed by a line 32 into an amplifier 33 which includes a sensitivity control for varying the coupling between two successive stages of the amplifier. The output from the amplifier 33 in turn is fed by a line 34 into an isolating cathode-follower circuit 35, which includes a gain control potentiometer. The circuit 35 is coupled by a line 36 with a cathode-follower output circuit 37 which includes a set point potentiometer. One end of the set point potentiometer of circuit 37 is connected to the tap of the gain potentiometer of circuit 35, with the result that a change in the gain setting inversely affects the absolute value of the set point potentiometer setting.

The signal from the output of circuit 37 is fed through lead 38 into a standard electric-pneumatic converter 39 which generates a pneumatic signal having a magnitude proportional to the amplitude of vibration of the blade 1. This pneumatic signal from converter 39 is fed by line 40 to a standard pressure controller 41, which is preadjusted to provide a little gain but maximum pneumatic reset. This controller 41 may be, for example, the unit made by the Taylor Instrument Company and known as the "Taylor Transet Indicator Controller," Model No. 338RF316. A source of 22 pound air supply 62 is connected to controller 41 through a line 63. The pneumatic output from the controller 41 is fed through line 42 to a valve positioner 43, which in turn adjusts the setting as needed of the control valve 48 through a mechanical coupling 44, to thereby maintain a constant amplitude of vibration of the blade 1 under inspection. A 22 pound source of air supply 60 is connected by a line 61 to valve positioner 43.

Prior to a typical operation of the amplitude controller, certain initial adjustments are made to insure proper automatic operation with a plurality of blades of the same design. These initial adjustments include selecting the types of flow nozzle 2 and electrodes 23 and 24 which best suit the blade to be inspected; positioning the blade 1 and the electrodes 23 and 24 to provide a spacing therebetween corresponding to a preferred value; setting

the regulated test pressure and the air flow to nozzle 2 at preferred values previously determined by experiment; and adjusting the amplitude control circuit settings, both electrical and pneumatic. as required to produce the desired amplitude of vibration as measured by means of a cathetometer not shown. Too much gain in the electronic control circuit will result in cyclic variation in the amplitude of vibration; this can be corrected by adjustment of both the electronic gain control of circuit 35 and the set point potentiometer of circuit 37, or by increasing the spacing between the blade 1 and the electrodes 23 and 24. Too little electronic gain will produce a "dead spot" in amplitude control. This can be eliminated by slowly increasing the gain potentiometer setting while decreasing the setting of the set point potentiometer, or by decreasing the spacing between the blade 1 and the electrodes 23 and 24.

In a typical operation of the amplitude controller, an incipient increase in the amplitude of vibration of the blade under test generates a proportional increase in the amplitude of the output from the bridge 27. This increase is in turn reflected through the electronic and pneumatic circuit, producing a proportional increase in the output pressure of the valve positioner 43. As a result, the control valve is adjusted to a position reducing the flow of air to the nozzle 2, and thus reducing the amplitude of vibration of the blade to near the initial value. The control arrangement operates in an analogous manner to offset incipient decreases in the amplitude of vibration.

The pneumatic controller 41 is incorporated in the control system as a means of providing "automatic reset" response without materially affecting the gain of the system. Automatic reset insures that the control point will remain essentially the same despite changes in load. The load will necessarily change to some extent when one blade is replaced by another since no two blades have identical characteristics.

In a typical test conducted with compressor blades of a certain type, the system of FIG. 2 maintained the amplitude of vibration virtually constant from blade to blade. In this test, the desired amplitude of full vibration was about 170 mils, measured at the blade tip. The spacing between the blade 1 and either of its associated electrodes 23 or 24 was about 100 mils. The frequency of the output from the bridge 27 averaged about 220 c.p.s. The pneumatic controller 41 was operated on maximum reset and the controller set point was left constant throughout the test.

The results obtained by this invention are much more reliable than prior art methods. For example, a certain degree of smoothness is desirable in the fillet region of axial flow compressor blades, and therefore some buffing of this region is permitted. Buffing causes surface metal to flow over surface defects or cracks and adversely affects the reliability of surface inspections, but has no apparent effect on the reliability of the instant invention. This conclusion has been supported by the finding that some blades which pass conventional dye penetrant inspection will, after exhibiting a decay in natural frequency in the test as made by the instant invention, fail to pass the same dye penetrant inspection, because vibratory stressing had caused the flowed metal to open sufficiently to permit penetration of the test dye into the defect.

The principles of this invention may be used to test the soundness of compressor blades after they have been installed in a compressor stator or rotor. Such a test would not only serve to test blade soundness, but in addition would detect if a blade has been properly seated in place. Also, this invention may be employed at the place where die cast blades are fabricated and the blades may then be tested on a production basis to separate sound from defective blades as soon as they are fabricated, before machine and other labor have been applied.



This invention has been described by way of illustration rather than limitation and it should be apparent that the invention is equally applicable in fields other than those described.

What is claimed is:

A device for inspecting non-destructively a compressor blade or the like for faults that will cause premature structural failure of said blade under vibratory service, comprising a support block supporting said blade, an air nozzle disposed closely adjacent to said blade, a source of air under pressure, a flow regulating valve, means feeding air from said source through said valve and to said air nozzle to thereby vibrate said blade for a selected test period, means disposed adjacent to said blade providing an output electrical signal that is of the same frequency as the frequency of vibration of said blade and that is proportional to the amplitude of vibration of said blade, means connected to said output electrical signal for converting said electrical signal to a pneumatic signal having a magnitude proportional to the amplitude of vibration of said blade, means responsive to said pneumatic signal and connected to said flow valve for continuously regulating the flow of air through said valve to thereby maintain a selected amplitude of vibration of said blade during said period, and means connected to said output electrical signal for measuring and indicating an excessive decay in said frequency of vibration below an allowable hysteretic decay during said test period as identification of a fault in said blade, said means for feeding air to said nozzle for a selected test period including a solenoid valve; and said means for measuring and indicating an excessive decay in said frequency of vibration comprising a series connected amplifier, filter, frequency multiplier, decade counter, analog converter and recorder, and memory and alarm unit; a timer and control unit having a push button control, said timer and control unit having a connection to said memory and alarm unit, a connection to said analog converter and recorder, and a connection to said solenoid valve, whereby said timer and control unit controls said solenoid valve to permit air to flow to said nozzle for said selected test period, and controls said analog converter and recorder and memory and alarm unit to thereby record a delayed initial frequency reading and a final frequency reading within said test period.

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