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(71) Applicant *(for all designated States except US):* DOW DEUTSCHLAND INC. [US/DE]; P.O. Box 1120, D-2160 Stade (DE).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)* : WALTER, Hilger, A. [DE/DE]; Im Ring 42 A, D-2160 Stade (DE). HÖNEN, Herwart [DE/DE]; Friedens Str. 11F, D-5132 Uebach-Palenberg (DE). GALLUS, Heinz, E. [DE/DE]; In der Schoenauer Aue 3, D-5100 Aachen (DE).

(74) Agent: SCHULTZ, Dale, H.; The Dow Chemical Company, Patent Department, P.O. Box 1967, Midland, MI 48641-1967 (US).

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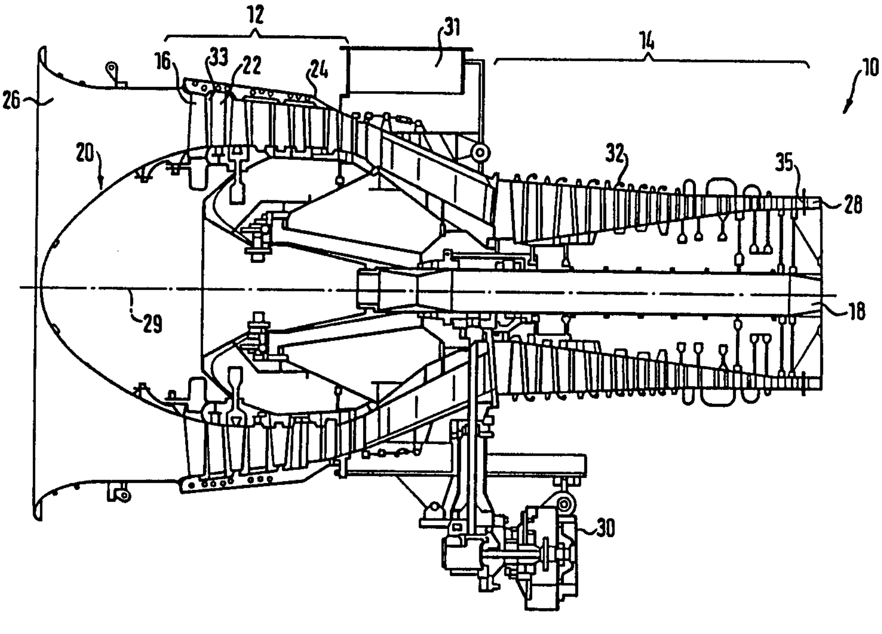

(57) Abstract

A process and a device for monitoring vibrational excitation of an axial compressor (10) by measuring of pressure fluctuation within at least one stage (12, 14) of said compressor (10) in the region of the compressor housing (24) by means of at least one pressure sensing device (32), checking whether each of said frequency signals comprises at least one excitation peak within a predetermined frequency interval in a region of at least one critical frequency of said compressor (10), determining at least one peak parameter indicative of the excitation status of the compressor (10) and generating a status change signal in case said peak parameter has a value lying beyond a predetermined value range.

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PROCESS AND DEVICE FOR MONITORING VIBRATIONAL EXCITATION OF AN AXIAL COMPRESSOR

FIELD OF THE INVENTION

The present invention relates to a process and a device for monitoring and controlling vibrational excitation of an axial compressor, said compressor comprising a rotor and a housing, said rotor being rotatably mounted within said housing for rotation about a rotational axis with variable or constant rotational speed, said compressor further comprising at least one compressor stage, each of said at least one stages comprising a row of rotor blades mounted on said rotor and being arranged one following the other in a circumferential direction with respect to said rotational axis and of a row of stator blades mounted on said housing and being arranged one following the other in a circumferential direction with respect to said rotational axis.

The invention provides for monitoring of vibrational excitations of either multi- or single stage compressors with the possibility of being able to control the compressor in accordance with the detected vibrational excitations. A compressor may be operated as an isolated unit or in conjunction with a power turbine engine, as would be the case in a power plant operation. The compressor may further be part of a gas turbine used for driving aeroplanes, ships or large vehicles.

BACKGROUND OF THE INVENTION

Compressors exist of a series of rotating or stationary blade rows in which the combination of a rotor (circular rotating blade row) and a stator (circular stationary blade row) forms one stage. Inside the rotor, kinetic energy is transferred to the gas flow (usually air) by the individual airfoil blades. In the following stator, this energy is manifested as a pressure rise in the gaseous air as a consequence of deceleration of the gaseous air flow. This deceleration of the gaseous air flow is induced as a result of the design of the stator section. The pressure ratio (exit pressure/ inlet pressure) of a single stage is limited because of intrinsic aerodynamic factors, so several stages are connected together in many turbo compressors to achieve higher pressure ratios than could be achieved by a single stage.

When operating an axial compressor, mechanical vibrations of compressor components, especially of rotor and stator blades, occur. An important cause for these mechanical vibrations are pressure fluctuations within the compressor stages.

The air fluid flow around each blade has an associated boundary layer which covers each blade and coheres to the blade in case of the rotor blades. The flow boundary layer associated with a rotor blade will rotate as an associated entity of the blade as the blade itself rotates. At the downstream edge of each blade, this flow boundary layer melds into an associated flow boundary entity known as the "delve or wake region" which is characterized by a localized reduction in both pressure and flow velocity. Therefore, each rotor produces at its downstream end a region with periodically changed flow and pressure characteristics at a characteristic frequency. This characteristic frequency is the product of the number of rotor blades and the present rotational speed. The frequency of these rotor- induced pressure fluctuations therefore depends on the rotational speed. The pressure fluctuations of the rotor of one stage interfere with the pressure fluctuations of the rotors of the neighboring stages. In case of different numbers of blades of these rotors, interference pressure fluctuations are produced with an interference frequency being either the difference or the sum of the characteristic frequencies of these rotors involved.

While both the stator blades and the rotor blades in the compressor are subject to damage from forces associated with vibrational excitation, the rotor blades are especially at risk because of the additional centrifugal forces that can interrelate with those forces caused by vibration. Depending on the blade constructions, at least one resonance frequency of vibrational blade excitation lies between 100 and 1000 Hz. The aforementioned characteristic frequencies lie within a range of 4000 Hz and more, when the compressor is operating at its operational rotation rate; the interference pressure fluctuations, however, have frequencies lying between 100 and 2000 Hz, too. Thus, there is the danger that, even in case of very slight variations of the compressor rotational speed during normal operation, the blades will be influenced to vibrate with their basic resonance frequency by the interference pressure fluctuations. The rotor or stator blades may then suffer damage or even break.

Contemporary turbo engines are usually equipped with fuel or energy control systems which measure and output a variety of operating parameters for the overall engine. Included in such control systems are highly accurate pressure sensing devices or systems. For example, pressure measuring systems are described in US Patent No. 4,322,977 entitled "Pressure Measuring System", filed May 27, 1980 in the names of Robert C. Shell, et al; US Patent No. 4,434,644 issued March 6, 1984, entitled "Pressure Ratio Measurement System", in the name of Frank J. Antonazzi; US Patent No. 4,422,355 issued December 27, 1983, entitled "Pressure Transducer"; US Patent No. 4,449,409, entitled "Pressure Measurement System With A Constant Settlement Time", in the name of Frank J. Antonazzi; US Patent No. 4,457,179, issued July 3, 1984, entitled "Differential Pressure Measuring System", in the name of J. Bluish et al and US Patent No. 4,422,125, issued December 20, 1983, entitled "Pressure Transducer With An Invariable Reference Capacitor", in the name of Frank J. Antonazzi et al.

While a wide variety of pressure measuring devices can be used in conjunction with the present invention, the disclosures of the above-identified patents are hereby expressly incorporated by reference herein for a full and complete understanding of the operation of the invention.

German Patent Publication (Auslegeschrift) 20 49 338 discloses the detection of mechanical vibrations of rotor blades. An electromagnetic sensor mounted to the compressor housing detects the passage of rotor blades by magnetic induction. In case of blade vibrations, the signal output of the sensor is a periodic wave with the characteristic frequency, but modulated by the vibrational frequency of the blades. An electronic circuitry extracts the modulation wave form from the sensor signal. By this known process, the actual induced mechanical vibrations of a single stage are measured. In cases of a highly resonant vibration excitation with a rapidly increasing vibration amplitude of the blade vibration, it is important that an eventual vibration excitation is detected as early as possible in order to take countermeasures in time. The known method of relying on the detection of mechanical vibrations is not suited to the challenge of early detection of unacceptable conditions since the fundamental causes of the vibrations can be in existence for some time before mechanical vibrations are detectable.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a process for online monitoring vibrational excitation of an axial compressor which provides for an early warning of vibrational excitations of compressor components.

It is a further object of the invention to provide a process for monitoring vibrational excitation of an axial compressor which enables prevention of the excitation of mechanical blade vibrations.

Another object of the invention is to provide a process for monitoring vibrational excitation of an axial compressor allowing an online monitoring with fast response, using common calculation techniques for the signal evaluation.

A further object of the invention is to provide a process for controlling an axial compressor such that the compressor can be operated with optimum efficiency near its load limits. One or more of these objects are solved by the process according to the invention, said process comprising the following steps:

a) measuring of pressure fluctuations within at least one of said compressor stages in the region of said housing by means of at least one pressure sensing device, each device delivering a sensor signal, respectively;
b) deriving a frequency signal from each of said sensor signals, said frequency signal being indicative of amplitudes of frequency components of said respective sensor signals in a respective frequency interval;
c) checking whether each of said frequency signals in a predetermined frequency interval comprises at least one excitation peak in a region of at least one critical frequency, and determining at least one peak parameter indicative of the form of said excitation peak, said critical frequency corresponding to resonance vibrational excitation frequencies of compressor components;
d) generating a first status change signal indicative of a change of operational status of said compressor in case of said peak parameter having a value lying beyond a determined value range.

According to the invention the frequency signal in the region of the predetermined critical frequency, is observed. In case of the occurrence of a peak of the frequency signal, the status change signal is generated. Thus, pressure fluctuations which are able to induce mechanical blade vibrations are detected as they occur that is before mechanical vibrations are actually induced. It is easy to observe several critical frequencies. Since the pressure fluctuations spread over the whole axial compressor, it is possible to monitor the axial compressor by only one pressure sensing device. The frequency signal may easily be derived from the frequency signals by using common evaluation techniques, for example fast Fourier transformation (FFT) or fast Hartley transformation (FHT). No model calculations are necessary.

For the process according to the invention, only the time varying part of the absolute pressure is of interest. The pressure fluctuations may directly be measured by means of a piezoelectric or piezoresistive pressure sensor, especially a piezocapacitive pressure sensor. Another less preferred pressure sensing device is a strain gauge pressure sensor.

The peak parameter indicative of the form of the characteristic peak may be the peak height. In this case, the parameter is easy to determine and easy to compare with a limit value or with the limits of an allowed region. In order to monitor the mechanical excitation of the most endangered components of the compressor, the critical frequency is defined as a torsional vibration basic frequency or a higher harmonic thereof or/and as a bending vibration basic frequency or a higher harmonic thereof.

In order to obtain observation of the very broad frequency region, the frequency interval is 0 to 20 000 Hz. A preferred region of the frequency interval is 100 to 2000 Hz, wherein most excitation frequencies during the operation of the compressor occur. In order to additionally monitor the mechanical vibration excitation of the compressor, at least one mechanical vibration sensing device may be mounted to the housing of the compressor.

To get information concerning the mechanical vibration excitation of the whole compressor, it is preferred to locate the mechanical vibration sensing devices near the axial ends of the housing. Additionally, a second status change signal is generated, indicative of an excess excitation status of said housing in case of said excess excitation status of the housing being detected, thereby giving an additional possibility of determining an excess excitation status of the compressor.

The invention further relates to a process for controlling of an axial compressor, which is based on the above- described process for monitoring of an axial compressor with the additional feature that at least one status change signal derived form said process is used for controlling said axial compressor. When, during the operation of the compressor, an increase of the excitation peak, lying in a predetermined frequency region, is detected or if the amount of a vibrational excitation, detected by at least one mechanical vibration sensing device mounted at the housing of the compressor increases, these increases may be used as an input for controlling the axial compressor in a way to move the operational status of the compressor in a direction where the predetermined frequency regions of the frequency signal do not contain any excitation frequencies or no mechanical excitations occur, so that a damage of compressor components may be avoided.

The invention further relates to a device for monitoring vibrational excitation of an axial compressor in accordance with the above described process for monitoring vibrational excitation of an axial compressor. The invention also relates to a device for controlling an axial compressor in accordance with the above mentioned process for controlling of vibrational excitation of an axial compressor.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention, reference is made to the following description and the drawings.

Figure 1	is a simplified graphic representation of an axial compressor as part of a gas turbine;
Figure 2	is a schematic representation of the compressor of Figure 1, illustrating one compressor stage of the compressor;
Figure 3	is a block diagram of the dynamic pressure probe connected to an evaluation unit;
Figure 4	is a Campbell diagram showing the torsional and bending resonance frequencies of a stage of a compressor as well as the excitation frequencies occurring in a compressor as a function of the rotational speed of the compressor; and

Figure 5 shows a frequency signal containing several excitation peaks.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings, wherein equal numerals correspond to equal elements throughout, first reference is made to Figures 1 and 2 wherein a typical compressor part of a gas turbine engine is depicted (including the present invention). The compressor 10 is comprised of a low pressure part 12 and a high pressure part 14. Rotor blades 16 of the compressor are mounted on a shaft 18 of a rotor 20. Stator blades 22 (guide vanes) are mounted in a housing (casing) 24 of said compressor 10 and are therefore stationary. Air enters at an inlet 26 of the gas turbine engine and is transported axially to compressor stages of the compressor under increasing pressure to an outlet 28. An axis 30 of said compressor is defined as the axis of rotation of the rotor 20.

Each of the mentioned compressor stages consists of two rows of blades with equal blade number, namely a row of rotor blades 16 and a row of stator blades 22. The blades of each row are arranged one following the other in a circumferential direction with respect to said axis 30. Figure 2 shows a first compressor stage of the compressor with rotor blades 16 and stator blades 22, which stage may be an intermediate stage in the high pressure part 14 of the compressor 10. The compressor 10, according to Figure 1, comprises an accessory gear box 30 enabling the adjustment of orientation of blades in order to change the load of the respective stages. Figure 1 further shows a bleed air collector 31 between the low pressure part 12 and the high pressure part 14. As the compressor, used in connection with the invention, is of common construction, it is not necessary to go into further detail.

According to the invention, a pressure sensing device in form of a dynamic pressure sensor 32 is mounted in the axial gaps between the rotor blades 16 and the stator blades 22 of the intermediate stage in the high pressure part 14 of the compressor 10. According to the most preferred embodiment, shown in Figures 1 and 2, this dynamic pressure sensor is mounted in the fourth stage of the high pressure part of compressor 10. An inlet opening 35 of the sensor 32 is flush with an inner circumferential surface 34 of a wall 36 defining said housing 24. Thus, sensor 32 measures the pressure fluctuations occurring at the inner circumferential surface 34. Since the sensor 32 is located in the region of the axial gap between the row of rotor blades 16 and stator blades 22, following the rotor blades downstream, the sensor 32 is sensitive for pressure fluctuations occurring in the air flowing through the compressor.

Instead of directly mounting the sensor 32 in an opening 40 (borescope hole), it is also possible to use an elongated adaptor (not shown) which, with one of its ends, is mounted to the opening 40 and, at its other end, carries the sensor.

The illustrated location of the sensor 32 at the fourth stage of the high pressure part of compressor 10 is preferred, because in this region the danger of blade damaging by vibrational excitation is very high. Additionally, in this region an observation of excitation frequencies in the air flow of the whole compressor may be achieved. Although not illustrated, further pressure sensors may be located in stages lying upstream or downstream of this stage, in order to obtain additional information about occurrence of excitation frequencies in the air flow. Dynamic pressure sensors, preferably piezoelectric pressure sensors, are used because of their reliability, high temperature operability and sensitivity for high frequency pressure fluctuations up to 20 000 Hz (for example Kistler Pressure Sensor, Type 6031).

Additionally, mechanical vibration sensing devices 33, 35 may be mounted at the housing 24. These mechanical vibration sensing devices 33, 35 additionally provide the possibility of observing a mechanical excitation status of the housing 24. Although not illustrated, the respective signals delivered from these sensors may be evaluated in the same way and by corresponding devices as illustrated later on for the signals delivered from the pressure sensors, thus giving an additional opportunity in monitoring and controlling the compressor.

As shown in Figures 2 and 3, the sensor is provided with an amplifier 42, amplifying the respective sensor signal. The amplifier 42 is connected via lines 44, 46 to an evaluation unit 48.

As shown in Figure 3, the evaluation unit 48 contains a fast Fourier transformer (FFT) analyzer 50 which receives signals from amplifier 42 through an analog digital converter ADC (or multiplexer) 52 which is connected between the amplifier 42 and the FFT analyzer 50.

The signals from the FFT analyzer are transmitted to a computer unit 54, comprising several subunits, amongst them a blade excitation detector 60. Besides this blade excitation detector 60 further detectors for the status of the compressor may be installed, for example a stall detector 58 for monitoring the operational status of the compressor 10 and a contamination detector 56 for detecting fouling of the compressor 10. However, the excitation monitoring, according to the present invention, may also be performed independently of stall detection and fouling detection.

In order to facilitate the computing of the frequency signals output from the FFT analyzer 50, a unit 62 for signal preparation may be connected between the FFT- analyzer 50 and the detectors 56, 58, 60. The unit 62 contains filter algorithms for handling and smoothing digital data as received from the FFT analyzer. The resulting frequency signals from the FFT analyzer, after smoothing via unit 62, are forwarded to said detectors 56, 58, 60 for comparison with respective reference patterns. If the comparison analyzers indicate deviations beyond a predetermined allowable threshold, the computed evaluation is transmitted to a status indicating unit 64 to indicate contamination or stall or blade excitation. Thus, the operation and status of compressor 10 can be monitored.

Independent of this monitoring, it is further possible to use the computed evaluation for controlling purposes. A respective compressor control unit 66, connected to the evaluation unit 48, is also shown in Figure 3 serving for controlling the compressor 10. In case of an unnormal status of the compressor, detected by one of the detectors 56, 58, 60, the compressor control unit 66 takes measures to avoid the risk of damaging the compressor 10, for example by lowering the load (adjustment of orientation of blades by means of gear box 30) or by reducing the fuel injection rate of the combustion engine to reduce the rotational speed. In some instances, the compressor control unit 66 may stop the compressor 10.

In detectors 56, 48, 60, the smoothed frequency signal is evaluated, said frequency signal being indicative of the amplitudes of frequency components of the respective sensor signal in a respective frequency interval.

As an example of the practical use of the invention, Figure 4 shows a Campbell diagram for a compressor stage (fourth stage) lying in the high pressure part of a compressor (General Electric Aeroderivative LM 5000), with abscissa indicating a rotational speed of the compressor and ordinate indicating the vibration frequencies. Several critical resonance frequencies of mechanical blade vibrations are indicated with horizontal lines. These frequencies correspond to the first bending excitation (frequency 1B) and first torsional excitation (frequency 1T) of the blades of this stage as well as higher harmonics of these excitations (2B, 3B, 4B; 2T). Further lines with a constant gain indicate frequencies of pressure fluctuations of the air flowing through the compressor. The primary pressure fluctuations are due to the wake regions at the downstream edge of each of the rotor blades which rotate with the rotor. Thus, their frequency is the present characteristic frequency (product of the number of rotor blades and present rotational speed of the rotor). The lines R1 to R5 correspond to the primary pressure fluctuations. The primary pressure fluctuations of the rotor stages interact with one another, thus producing secondary pressure fluctuations with the common known beat frequencies (sum value and difference value of the frequencies of the interacting primary pressure fluctuations). In Fig. 4, some lines indicative of the lowest beat frequencies, depicted as lines R1-R2, R4-R1, R5-R3, R4-R3 and R5-R4, correspond to the secondary pressure fluctuations with the difference frequencies of the respective interacting primary pressure fluctuations (characteristic frequency of the first stage minus characteristic frequency of the second stage etc.)

According to Figure 4, in a low frequency range 75, containing the first and second bending excitation (1B,2B) and the first torsional excitation (1T) of the blades, the highest density of excitation frequencies occurs over the whole region of the rotational speed of the compressor. Thus, there is a high probability that resonance blade excitations are induced within this frequency range 75 in the whole operating speed range of the compressor.

Accordingly, the frequency signal is preferably observed in this low frequency region with respective occurrence of pressure fluctuations with critical frequencies corresponding to certain resonance frequencies of the blades. In the region of each of the critical frequencies (1B, 2B, 1T), a predetermined frequency range 76, 78, 80 is set. During monitoring the vibrational excitation of the compressor, the signals are analyzed to determine the existence of frequency components in these predetermined ranges 76, 78, 80. A value, indicative of the height of a peak lying in one of these predetermined frequency ranges 76, 78, 80, is derived and monitored for an increase in its height. When performing the measurement leading to Fig. 5, the rotational speed was set to a value indicated by line V in Fig. 4. In Fig. 5, a frequency signal is illustrated, containing excitation peaks R5-R4, R4-R3, R3-R1, R5-R3, R4-R1, R1-R2 corresponding to the secondary pressure fluctuations, shown in Fig. 4 as lines R5-R4, R4-R3, R3-R1, R5-R3, R4-R1, R1-R2. The frequency ranges 76, 78, 80 correspond to the respective frequency ranges in Fig. 4. For each of the predetermined frequency ranges 76, 78, 80 a predetermined threshold value 70, 72, 74 is set. These predetermined threshold values 70, 72, 74 may be different for each of the critical resonance frequencies of the rotor components, because the danger of causing damage to the rotor components may be different for different resonance vibrational excitations. If during the operation of the compressor at least one of the excitation peaks R5-R4, R4-R3, R3-R1, R5-R3, R4-R1, R1-R2 shifts into one of the predetermined frequency ranges 76, 78, 80 and if the height of this at least one excitation peak exceeds the corresponding threshold value 70, 72 and 74, respectively, a status change signal is generated by the blade excitation detector and is delivered to the status indicating unit 64, thus indicating the appearance of dangerous pressure fluctuations in the air flowing through the compressor.

Thus, during monitoring the vibrational excitation of a compressor, the occurrence of pressure fluctuations in the air flowing through the compressor is observed. The threshold values for pressure fluctuations in the region of critical frequencies may be set to very low values, thus being able to indicate the appearance of pressure fluctuations having frequencies in the range of a critical frequency before any excitations of compressor components can take place.

The detection of such excitation frequencies may also be used for closed loop control of the compressor. If the measured height of the at least one excitation peak exceeds the corresponding threshold value in the region of a critical resonance frequency, the compressor control unit 66 receives the respective control signal in order to increase or decrease the rotational speed of the compressor to leave an operational status wherein one of the excitation frequencies, depending on the rotational speed as shown in Figure 4, equals an excitation resonance frequency of the rotor components.

CLAIMS:

1. Process for monitoring vibrational excitation of an axial compressor (10), said compressor comprising a rotor and a housing, said rotor being rotatably mounted within said housing for rotation about a rotational axis with variable or constant rotational speed, said compressor further comprising at least one compressor stage, each of said at least one stages comprising a row of rotor blades mounted on said rotor and being arranged one following the other in a circumferential direction with respect to said rotational axis and of a row of stator blades mounted on said housing and being arranged one following the other in a circumferential direction with respect to said rotational axis,said process comprising the following steps:

a) measuring of pressure fluctuations within at least one of said compressor stages in the region of said housing by means of at least one pressure sensing device, each device delivering a sensor signal, respectively;

b) deriving a frequency signal from each of said sensor signals, said frequency signal being indicative of amplitudes of frequency components of said respective sensor signals in a respective frequency interval;

c) checking whether each of said frequency signals in a predetermined frequency interval comprises at least one excitation peak in a region of at least one critical frequency, and determining at least one peak parameter indicative of the form of said excitation peak, said critical frequency corresponding to resonance vibrational excitation frequencies of compressor components;

d) generating a first status change signal indicative of a change of operational status of said compressor in case of said peak parameter having a value lying beyond a determined value range.

2. Process according to claim 1, wherein said pressure sensing device is arranged at said housing between the rotor blades and the stator blades of one of said compressor stages.

3. Process according to claim 1, wherein said frequency signal is obtained by fast Fourier transformation (FFT).

4. Process according to claim 1, wherein said frequency signal is obtained by fast Hartley transformation (FHT).

5. Process according to claim 1, wherein said pressure sensing device comprises a piezoelectric or piezoresistive pressure sensor.

6. Process according to claim 1, wherein said peak parameter is indicative of the peak height of the excitation peak.

7. Process according to claim 6, wherein the peak height is defined as the ratio of a difference of a maximum value of said frequency signal in the region of said critical frequency and a mean value of said frequency signal within a predetermined frequency range about said critical frequency to said mean value.

8. Process according to claim 1, wherein said critical frequency is defined as a torsional vibration basic frequency of said blades.

9. Process according to claim 8, wherein said critical frequency is defined as a higher harmonic of said torsional vibration basic frequency.

10. Process according to claim 1, wherein said critical frequency is defined as a bending vibration basic frequency of said blades.

11. Process according to claim 10, wherein said critical frequency is defined as a higher harmonic of said bending vibration basic frequency.

12. Process according to claim 1, wherein said frequency interval is 0 Hz - 20 000 Hz.

13. Process according to claim 12, wherein said frequency interval is 100Hz - 2000Hz.

14. Process according to claim 1, wherein at least one mechanical vibration sensing device is mounted at said housing detecting a mechanical vibration excitation of said housing.

15. Process according to claim 14, wherein said at least one mechanical vibration sensing device is located near an end of said housing.

16. Process according to claim 15, wherein a second status change signal is generated, indicative of an excess excitation status of said housing in case of said mechanical vibration sensing device detecting an excess vibrational excitation status of said housing.

17. Process for controlling vibrational excitation of an axial compressor (10), said compressor comprising a rotor and a housing, said rotor being rotatably mounted within said housing for rotation about a rotational axis with variable or constant rotational speed, said compressor further comprising at least one compressor stage, each of said at least one stages comprising a row of rotor blades mounted on said rotor and being arranged one following the other in a circumferential direction with respect to said rotational axis and of a row of stator blades mounted on said housing and being arranged one following the other in a circumferential direction with respect to said rotational axis, said process comprising the following steps:

a) measuring of pressure fluctuations within at least one of said compressor stages by means of at least one pressure sensing device, each device delivering a sensor signal, respectively;

b) deriving a frequency signal from each of said sensor signals, said frequency signal being indicative of amplitudes of frequency components of said respective sensor signals in a respective frequency interval;

c) checking whether each of said frequency signals in a predetermined frequency interval comprises at least one excitation peak in a region of at least one critical frequency, and determining at least one peak parameter indicative of the form of said excitation peak, said critical frequency corresponding to resonance vibrational excitation frequencies of compressor components;

d) generating a first status change signal indicative of an excitation status of said blades in case of said peak parameter having a value lying beyond a determined value range;

e) using said first status change signal for controlling said axial compressor.

18. Process according to claim 17, wherein at least one mechanical vibration sensing device is mounted at said housing detecting a mechanical vibration excitation of said housing and wherein a second status change signal is generated, indicative of an excess excitation status of said housing in case of said mechanical vibration sensing device detecting an excess vibrational excitation status of said housing, said second status change signal being used for controlling said axial compressor.

19. Process according to claim 18, wherein said at least one mechanical vibration sensing device is located near an end of said housing.

20. Device for monitoring vibrational excitation of an axial compressor said compressor comprising a rotor and a housing, said rotor being rotatably mounted within said housing for rotation about a rotational axis with variable or constant rotational speed, said compressor further comprising at least one compressor stage, each of said at least one stages comprising a row of rotor blades mounted on said rotor and being arranged one following the other in a circumferential direction with respect to said rotational axis and of a row of stator blades mounted on said housing and being arranged one following the other in a circumferential direction with respect to said rotational axis, said device comprising at least one pressure sensing device for measuring of pressure fluctuations within at least one of said compressor stages, said pressure sensing device delivering a sensor signal, at least one transformation unit for deriving a frequency signal from each of said sensor signals, said frequency signal being indicative of amplitudes of frequency components of said respective sensor signals in a respective frequency interval, a peak evaluation unit being adapted for checking whether each of said frequency signals comprises at least one excitation peak in a region of a predetermined critical frequency assigned to a mechanical vibration excitation status of said compressor, said critical frequency corresponding to resonance vibrational excitation frequencies of compressor components, respectively and determining at least one peak parameter signal indicative of the form of said excitation peak, and for generating a first status change signal in case of said peak parameter signal having a value lying beyond a determined value range, a status indicating unit receiving said first status change signal and indicating the respective operational status of said compressor.

21. Device according to claim 20, wherein said pressure sensing device is arranged at said housing between the rotor blades and the stator blades of one of said compressor stages.

22. Device according to claim 20, wherein said pressure sensing device comprises a piezoelectric or piezoresistive pressure sensor.

23. Device according to claim 20, wherein said transformation unit comprises a fast Fourier transformation unit.

24. Device according to claim 20, wherein said transformation unit comprises a fast Hartley transformation unit.

25. Device according to claim 20, wherein at least one mechanical vibration sensing device is mounted at said housing.

26. Device according to claim 25, wherein said at least one mechanical vibration sensing device is located near an end of said housing.

27. Device according to claim 25, wherein a signal evaluation unit is connected to said mechanical vibration sensing device, generating a second status change signal in case of said housing lying in an excess vibrational excitation status.

28. Device according to claim 27, wherein a status indicating unit is provided, receiving said second status change signal and indicating the respective operational status of said compressor.

29. Device for controlling vibrational excitation of an axial compressor said compressor comprising a rotor and a housing, said rotor being rotatably mounted within said housing for rotation about a rotational axis with variable or constant rotational speed, said compressor further comprising at least one compressor stage, each of said at least one stages comprising a row of rotor blades mounted on said rotor and being arranged one following the other in a circumferential direction with respect to said rotational axis and of a row of stator blades mounted on said housing and being arranged one following the other in a circumferential direction with respect to said rotational axis, said device comprising at least one pressure sensing device for measuring of

pressure fluctuations within at least one of said compressor stages, said pressure sensing device delivering a sensor signal, at least one transformation unit for deriving a frequency signal from each of said sensor signals, said frequency signal being indicative of amplitudes of frequency components of said respective sensor signals in a respective frequency interval, a peak evaluation unit being adapted for checking whether each of said frequency signals comprises at least one excitation peak in a region of a critical frequency assigned to a mechanical vibration excitation status of said compressor, respectively and determining at least one peak parameter signal indicative of the form of said excitation peaks, and for generating a first status signal in case of said peak parameter signal having a value lying beyond a determined value range, a status indicating unit receiving said first status change signal and indicating the respective operational status of said compressor, a first controlling unit being supplied with said first status change signal for operational control of said axial compressor.

30. Device according to claim 29, wherein said pressure sensing device is arranged at said housing between the rotor blades and the stator blades of one of said compressor stages.

31. Device according to claim 29, wherein said pressure sensing device comprises a piezoelectric or piezoresistive pressure sensor.

32. Device according to claim 29, wherein said transformation unit comprises a fast Fourier transformation unit.

33. Device according to claim 29, wherein said transformation unit comprises a fast Hartley transformation unit.

34. Device according to claim 29, wherein at least one mechanical vibration sensing device is mounted at said housing.

35. Device according to claim 34, wherein said at least one mechanical vibration sensing device is located near an end of said housing.

36. Device according to claim 34, wherein a signal evaluation unit is connected to said mechanical vibration sensing device, generating a second

status change signal in case of said housing lying in an excess vibrational excitation status.

37. Device according to claim 36, wherein a status indicating unit is provided, receiving said second status change signal and indicating the respective operational status of said compressor.

38. Device according to claim 37, wherein a second controlling unit is provided being supplied with said second status change signal for operational control of said axial compressor.

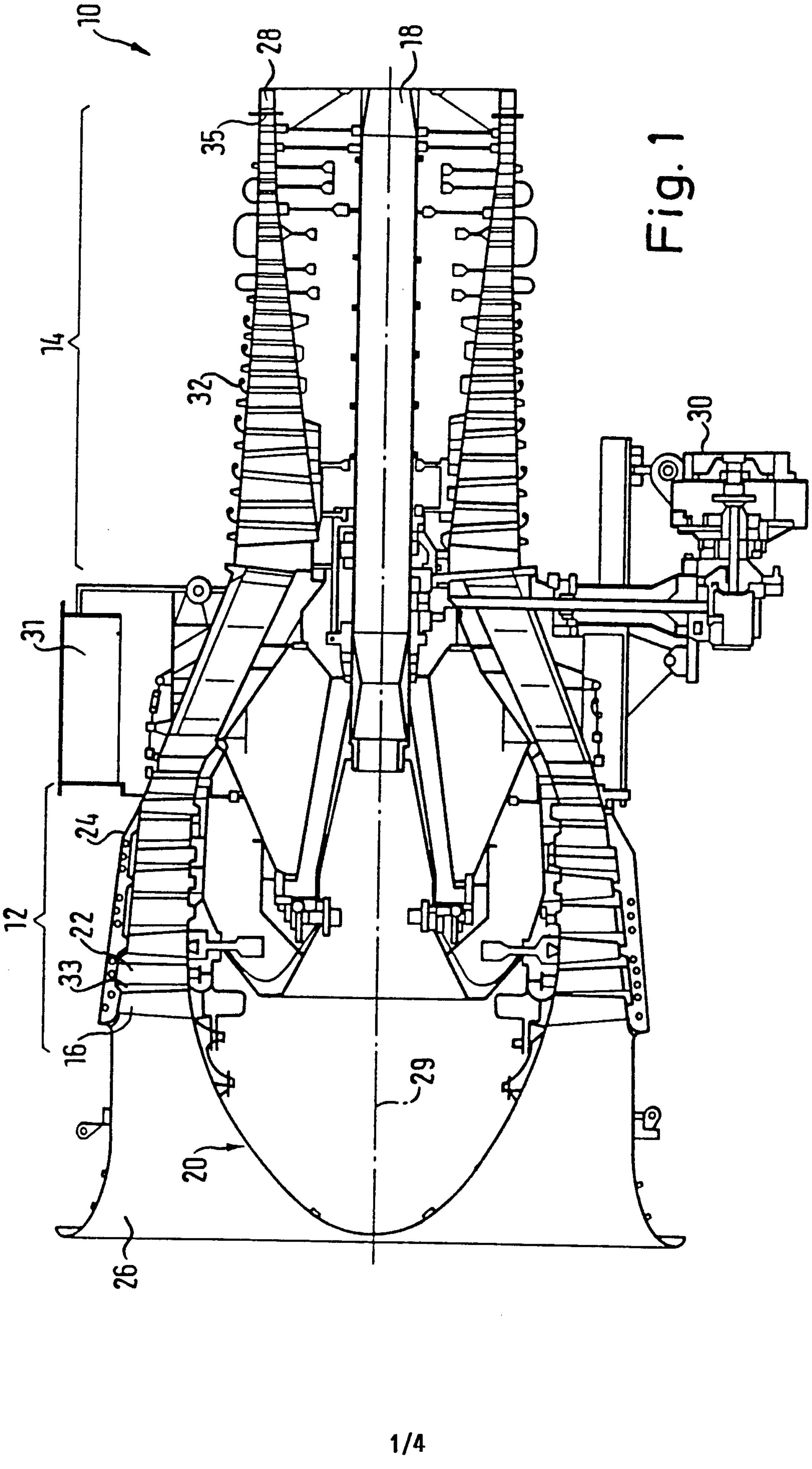
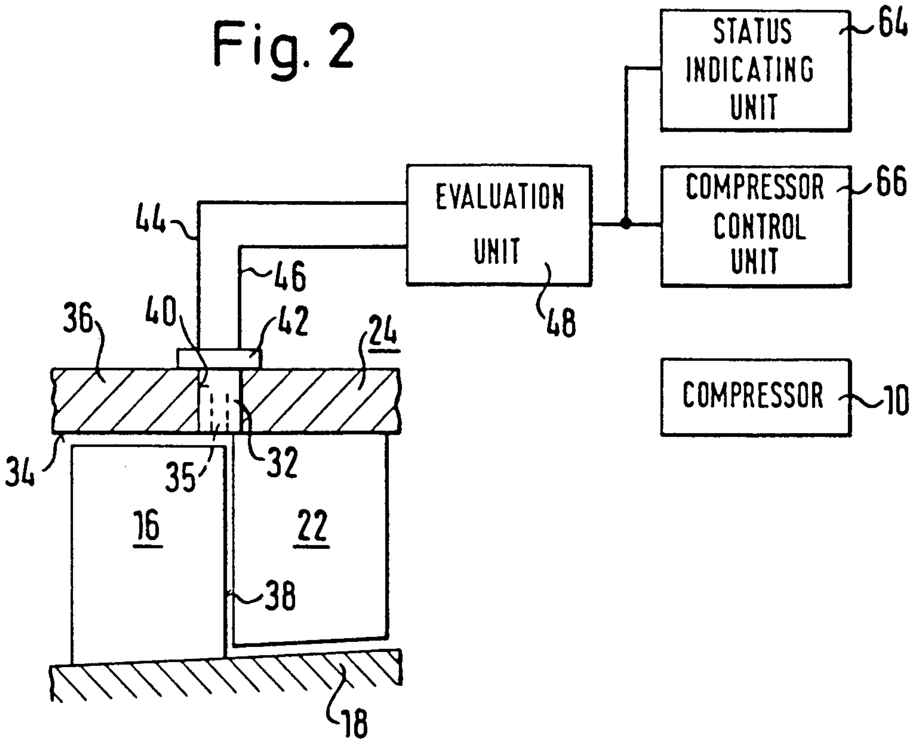


Fig. 1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EVALUATION UNIT
COMPRESSOR CONTROL UNIT
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44
46
48
36
40
42
24
COMPRESSOR
10
34
35
32
16
22
38
18

Fig. 2

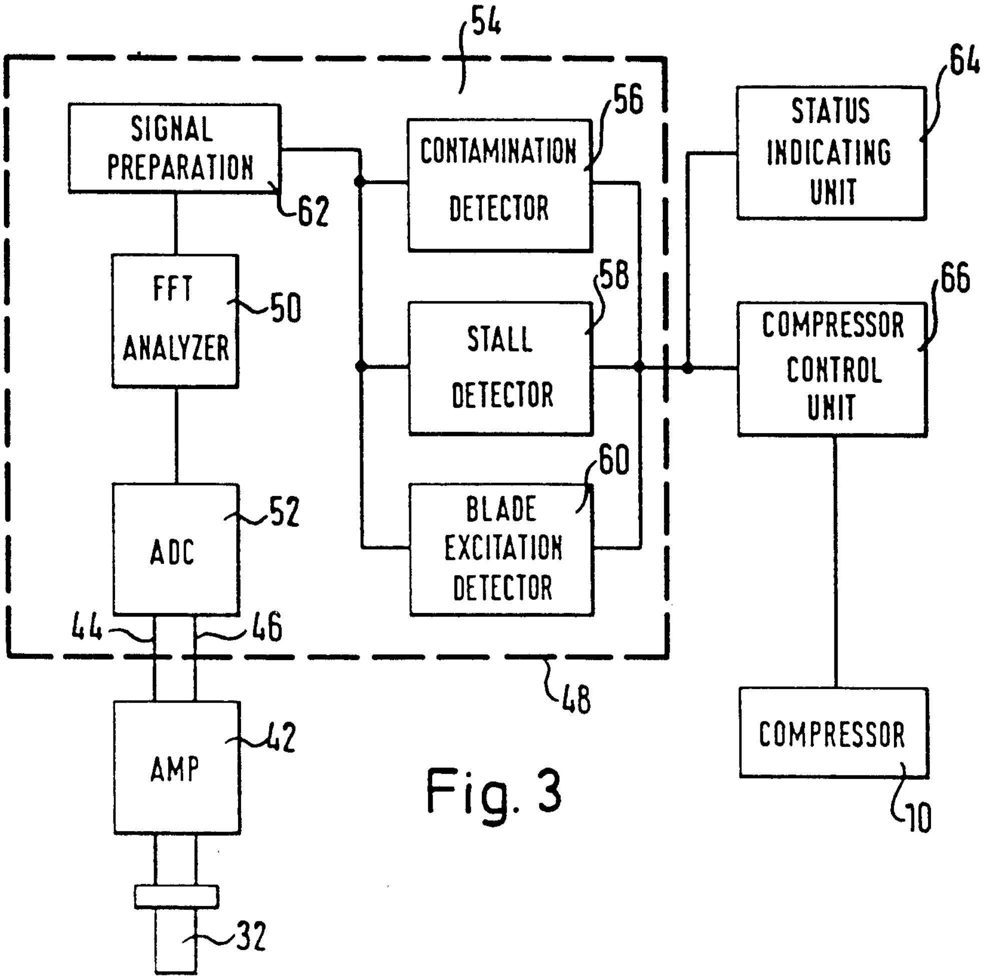
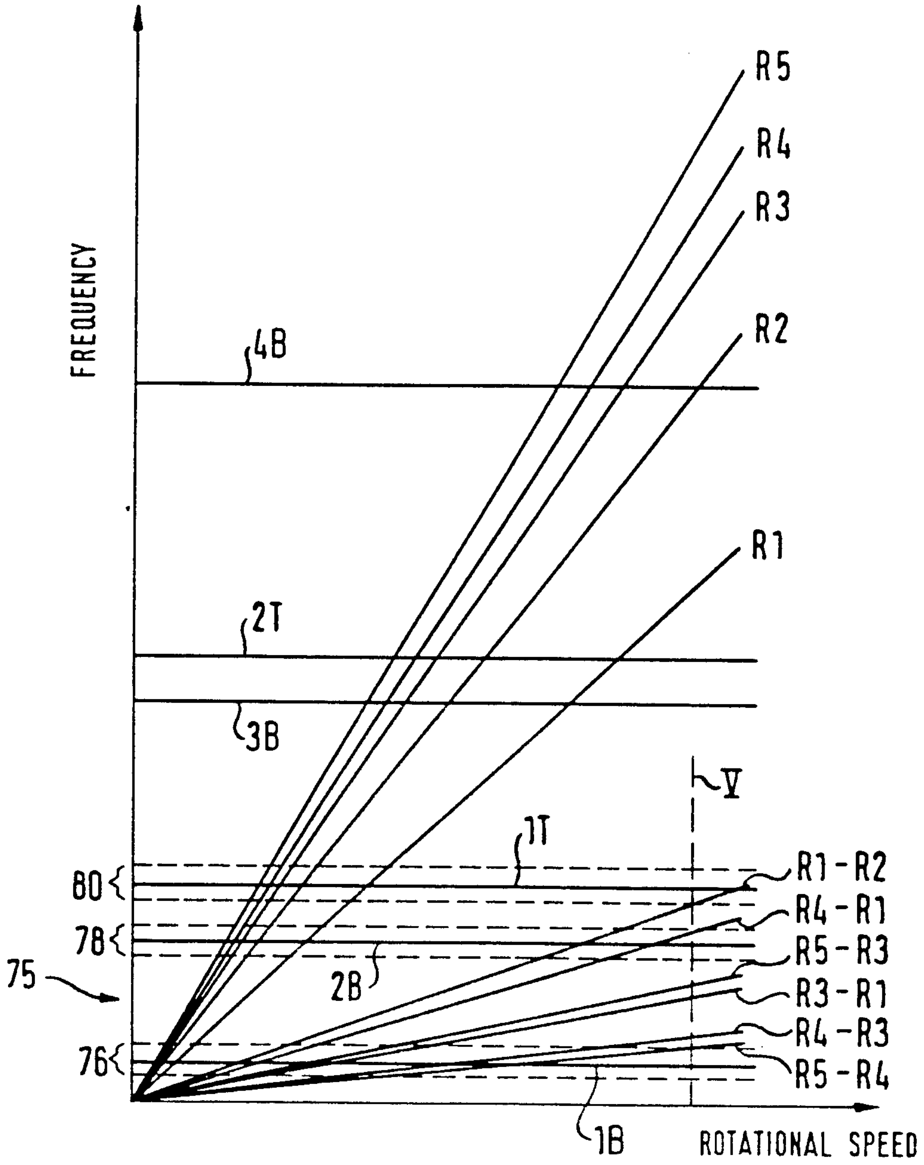

54
64
SIGNAL PREPARATION
56
CONTAMINATION DETECTOR
STATUS INDICATING UNIT
62
FFT ANALYZER
50
58
STALL DETECTOR
66
COMPRESSOR CONTROL UNIT
ADC
52
60
BLADE EXCITATION DETECTOR
44
46
48
AMP
42
COMPRESSOR
10
32

Fig. 3

FIG. 4


FREQUENCY
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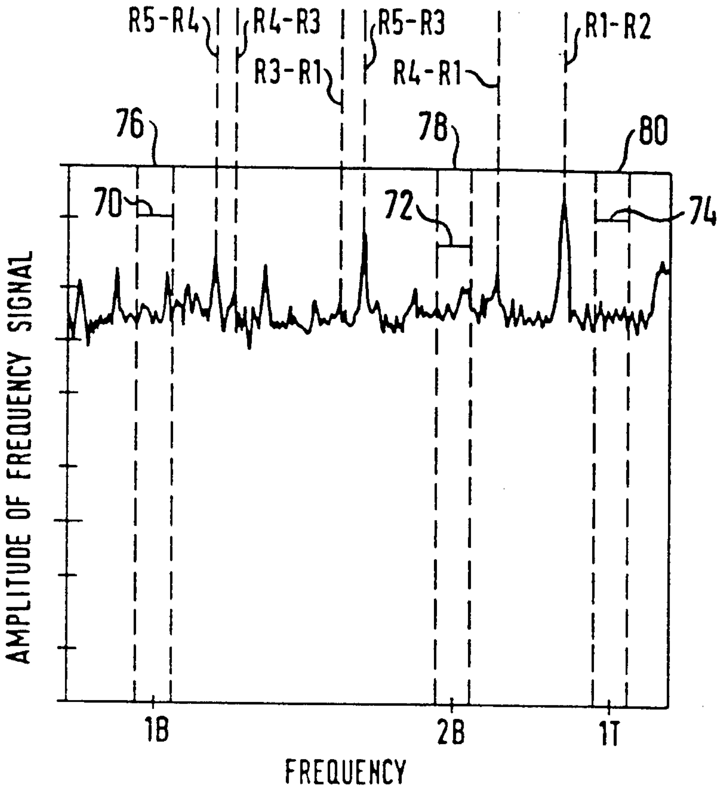
R4
R3
R2
R1
4B
2T
3B
V
1T
80
78
75
2B
76
1B
R1-R2
R4-R1
R5-R3
R3-R1
R4-R3
R5-R4
ROTATIONAL SPEED

Fig. 5


R5-R4
R4-R3
R5-R3
R3-R1
R4-R1
R1-R2
76
78
80
70
72
74
AMPLITUDE OF FREQUENCY SIGNAL
1B
2B
1T
FREQUENCY

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/05766

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :G06F 15/20
US CL :364/558, 431.02, 508; 73/660; 415/26
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 364/558, 431.02, 508, 505, 494; 73/660, 115, 116; 415/26; 417/20, 43; 60/39.29

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,989,159 (Liszka et al.) 29 January 1991, col. 1 lines 5-7, col. 2 lines 17-62.	1, 3-6, 14, 15, 17, 20, 22-26, 29, 31-35
Y	US, A, 4,196,472 (Ludwig et al.) 1 April 1980, col. 2 line 19-col. 4 line 67.	1-6, 14, 15, 17, 20-26, 29-35
Y	US, A, 4,252;498 (Radcliffe et al.) 24 February 1981, col. 2 line 46-col. 4 line 23.	1-6, 14, 15, 17, 20-26, 29-35

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search
01 DECEMBER 1993

Date of mailing of the international search report
11 JAN 1994

Name and mailing address of the ISA/US
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Box PCT
Washington, D.C. 20231
Facsimile No. NOT APPLICABLE

Authorized officer
KEVIN J. TESKA
Telephone No. (703) 305-9787

International application No.
PCT/US93/05766

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Us, A, 4,618,856 (Antonazzi) 21 October 1986, col. 3 line 40-col. 5 line 46.	1, 3-6, 14, 15, 17, 20, 22-26, 29, 31-35
A,P	US, A, 5,165,845 (Khalid) 24 November 1992, the entire document.	1-38
A	US, A, 4,216,672 (Henry et al.) 12 August 1980, the entire document.	1-38
A	US, A, 4,604,702 (Zwicke) 5 August 1986, the entire document.	1-38
A	US, A, 4,625,280 (Couch) 25 November 1986, the entire document.	1-38