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(54) Benævnelse: **Fremgangsmåde og indretning til vibrationsanalyse samt mønsterdatabaser derfor og anvendelse af en mønsterdatabase**

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FIELD OF THE INVENTION

[0001]
The invention concerns a method and a device for the analysis of a vibration spectrum occurring during the use of a component, in the testing of a component, and/or during the processing of a workpiece by machining, welding, forming, joining and/or separating, or similar. The invention further concerns a pattern database for this purpose and its use.

BACKGROUND TO THE INVENTION

[0002]
In the prior art many methods for the observation of the processing of workpieces by machine are of known art.

[0003]
Thus from DE 10 2005 034 768 A1 a method for the monitoring of the operational state of a machine tool is of known art, so as to diagnose critical states ahead of any occurrence of an incidence of damage and thus to avoid the costs and labour caused by damage and unplanned failures. In the methods of known art rotating components of a machine tool such as for example the rotors of cutting tool or motor spindles, pumps, or fans are monitored by means of a vibration sensor.

For this purpose low-frequency vibrations are registered by a vibration sensor in order to detect out-of-balance and/or cutting tool vibrations, and thus e.g. to detect a poorly balanced, incorrectly clamped, or worn cutting tool. Here the evaluation takes place graphically on the basis of individual values of signal amplitudes at prescribed frequencies. However, such an evaluation of individual low-frequency vibrations, as is also of known art from DE 102 44 426 D4 and DE 103 40 697 A1, is only suitable to a limited extent for the evaluation of a machining process with regard to the quality of the processing of the workpiece.

[0004]
For the optimisation of a machining process it is of known art from DE 698 04 982 T2 to register low-frequency vibrations during the processing of the workpiece and, as a function of information concerning the cutting tool, to specify

standard values for the rotational speed of the cutting tool, with which undesirable vibrations, which are known as chatter, can be avoided or reduced.

[0005]
DE 44 05 660 A1 is likewise concerned with the reduction or prevention of such chatter that is registered via a vibration sensor, and for this purpose makes use of a control mechanism.

[0006]
From D 94 03 901 an arrangement of vibration sensors for the capture of signals from the machining process is of known art. Here a structure-borne sound sensor is attached to a probe arm, which is in contact with the workpiece, such that sound signals, i.e. chatter vibrations generated from the machining process are transferred from the workpiece onto the sensor. In this context D 94 03 901 talks of high-frequency sound signals. However, the term "high-frequency" is used in the context of DE 38 29 825 A1, which feeds a range of frequencies between 20 kHz and 2 MHz into an averaging process. Even this range of frequencies can hardly be transferred and detected via the probe arm coupling of D 94 03 901.

[0007]
From DE 44 36 445 A1 a method for the evaluation of machining processes is of known art, in which vibrations/structure-borne sound signals of a cutting tool are registered firstly under load and secondly at the same rotational speed under no-load conditions, and at each rotational speed a one-dimensional comparison is executed of the corresponding vibration frequencies when operating under no-load conditions and under load, so as to evaluate the cutting tool.

[0008]
WO 2006/114242 discloses a method of a two-dimensional vibration analysis that continually compares the signal power with a reference value and reports a misalignment when a malfunction occurs.

[0009]
In both WO 88/07911 and WO 89/12528 a cutting tool with an integrated sound sensor is of known art, which delivers a one-dimensional voltage signal that is proportional to the vibration frequency.

[00010]
In DE 38 29 825 C2 during processing of a workpiece by chip removal the signal level of a sound sensor is registered as a function of frequency and averaged over periods of time. A comparison of the average values with threshold values or design values leads to conclusions concerning the quality of the tool or the process.

[0011]
All methods of known art are subject to the disadvantage that the cutting tool and the machining process can only be evaluated to an inadequate extent.

[0012]
Moreover the methods of known art are limited to machining processes.

[0013]
In the prior art no reliable sound-based methods for the observation of other treatment processes, such as, for example, welding (laser welding, electrical welding, etc.), forming, joining and/or separating, or similar, are of known art.

[0014]
Thus at the present time optical systems are deployed for the monitoring of a laser process; these measure the light reflected from the point of impingement and from the spectrum and the intensity attempt to derive how the actual laser process is absorbed by the material. With this method satisfactory results cannot always be achieved, since several materials are to be joined together, and the process of full penetration welding, that is to say, whether the laser energy also brings about the necessary melting and thermal penetration of all components, cannot be checked by means of laser emissions reflected from the surface.

[0015]
Moreover in the prior art no reliable sound-based methods for the observation of components in operation, such as, for example, a steel wheel of a railway wagon during the operation of a train, or a component of an engine during operation,

are of known art. The avoidance of component failures is vital, in particular in the case of safety-relevant applications such as, for example, in the transport of passengers by means of e.g. trains, aircraft, and motor vehicles, or in plants with potential hazards such as, for example, power stations and is only possible with at high cost by means of regular tests when the vehicles or plants are not in operation.

SUMMARY OF THE INVENTION

[0016]
On this basis the object underlying the invention is therefore to create a method and a device for purposes of vibration analysis, in particular sound analysis, and also a pattern database for this purpose, and use of a pattern database for vibration analysis, with which precise observation and/or assessment of a component, workpiece, cutting tool and/or treatment process is enabled.

[0017]
This object is achieved in accordance with the features of Claims 1, 11, 14 and 15.

[0018]
Accordingly a method for purposes of vibration analysis is created in which vibrations of a component, or a workpiece, or a tool are registered and evaluated, wherein a vibration spectrum is registered at various times, or continuously, and is subjected to a multi-dimensional evaluation.

[0019]
Here the vibrations can occur during the use of a component such as, for example, a steel wheel, or an axle, of a train in operation, during the testing of a component in an installed or an uninstalled state, if necessary with vibrational excitation from an external source by means of tapping or sound coupling, or from movement, etc., and/or during the processing of a workpiece by means of machining, welding, forming, joining and/or separating, or similar. The use of a vibration analysis for each of these individual applications and for other technically comparable applications is in each case of independent inventive significance.

[0020]
The inventive registering of the vibration spectrum at various times and preferably continuously, or quasi-continuously, with an appropriate sample rate, allows for a multi-dimensional data evaluation, which is the basis for a precise assessment of a component, workpiece, tool, and/or process.

[0021]
For a preferred form of embodiment with three dimensions the multi-dimensional data evaluation can be illustrated, for example, in terms of a landscape, which can then, e.g., extend through a space spanned by a frequency axis, a time axis, and an amplitude axis. The landscape visualises the sound emissions over time and has characteristic features, which in each case form a kind of “fingerprint”. These characteristic features can be determined with suitable methods. Similarly deviations from these characteristic features can be determined. Also characteristic features can be determined in the multi-dimensional data for particular faults or types of faults. Overall on the basis of the multi-dimensional data, which in the preferred form of embodiment form a landscape in the frequency-time-amplitude space, the quality of a machining process of a workpiece can be determined with a high level of reliability, in particular in real time while processing is in progress, and in fact universally for a large number of treatment processes such as, for example, machining, welding, forming, joining, separating, and/or similar. The degree of wear on the cutting tool, or a cutting tool fault such as, for example, a drill fracture, can also be determined and identified on the basis of the appropriate characteristic features. Finally in the case of component testing the deviation from the anticipated characteristic features can be determined, and a particular fault or type of fault can be diagnosed in terms of conformity with fault characteristics. Here the component testing can even be carried out while the component is in operation, e.g. a vibration spectrum, and in particular a sound emission spectrum, can be captured on the axle or wheel while a train is in operation, and can be checked for characteristic features, in order, for example, to determine wear, the level of wear, a fault, such as, for example, a fracture or a crack, or else to determine standard behaviour, or, more generally, any deviation from standard behaviour.

[0022]
The evaluation is preferably executed in an automated manner on the basis of pattern recognition. For multi-dimensional pattern recognition, and in particular

three-dimensional pattern recognition, suitable algorithms can be used, which can be implemented quickly and reliably on a computer with adjustable recognition parameters, and can access stored vibration spectrum data, or process the vibration spectrum data in real time.

[0023]
A pattern database with suitable patterns for a particular application is advisably provided. Here the patterns can be stored in the form of sections of pattern landscapes, if necessary with ranges of tolerance, and/or can be defined in terms of functions. This enables on the one hand the use of prescribed patterns for a particular application or class of applications, e.g. patterns for a particular step in a drilling process. Moreover data can be collected during a learning phase and stored as patterns, with tolerance values as necessary. Thus for example the sound emission spectrum can be registered during the drilling process and workpiece changeover and cutting tool changeover, and patterns can be extracted from it, on the basis of which the evaluation of subsequent processes can be executed. With this an individual adaptability of the pattern to, e.g., a particular process, or a particular processing machine, or a particular component, or a particular testing situation for a component, is possible in a simple manner, and is automated as necessary. Here the patterns can cover ranges of values in order to define tolerable deviations and/or to simplify the detectability.

[0024]
For an automated evaluation provision is preferably made for an envelope of the registered vibration spectrum or sections of the latter to be formed, and compared with a comparative envelope. Here the envelope is formed, for example, via a smoothing function, from averaging data points adjacent in space, or by using appropriate methods for the smoothing of multi-dimensional data. The deviation between the envelope and the comparative envelope can be used as a measure for an assessment of a component, workpiece, tool and/or process, e.g. of the quality of a machining process. Moreover it allows the use of an envelope, elements of the process such as, for example, workpiece contact, or a particular process, to be identified in an automated manner. Moreover pattern recognition is simplified by the use of an envelope, and the detection rate is improved.

[0025]
The vibration spectrum is preferably registered and evaluated at high frequencies and/or over a large bandwidth.

[0026]
A large bandwidth is advisable, since characteristic features can occur in regions of the sound emission spectrum that are spaced far apart from one another in frequency. Thus crack initiation has a high frequency "fingerprint", while a drill fracture leaves relatively low frequency features in the sound emission spectrum, and a machine fault such as, for example, out-of-true running of a lathe, leaves characteristic features in the low-frequency region of the vibration spectrum. The whole frequency spectrum of the vibrations is preferably registered, for which purpose various sensors can be provided as necessary to cover various frequency ranges. In the preferred form of embodiment just one sensor is used, namely a sound sensor, in other forms of embodiment, however, other vibration sensors can also be used additionally or alternatively.

[0027]
The high-frequency registering advantageously also enables an assessment of microscopic processes on or in the component, or workpiece, or tool.

[0028]
Thus, for example, when machining a solid body elements of material are torn out of their positions against their bonding forces. The force necessary for this purpose is applied by means of a cutting tool. The bonding forces exist between microscopically small elements. The machining process can therefore also be understood as a sequence of microscopic separations. Each of these small separations sends an impulse through the adjacent material. Vibrations occur as a result of these impulses. The vibration frequencies are functions of the duration of the impulse and the elasticity of the material. Here each machining process consists of a sequence of very many microscopic separations, that is to say, a sequence of many small impulses. These impulses occur as a sequence in time. After one microscopic separation has taken place a separation force builds up once again on the next material particles that are still bonded together in the path of the cutting tool. When the necessary separation force is exceeded the next impulse occurs. In this manner new vibrational excitations continue to arise; their distribution in time is a function of the cutting speed and the size of the material particles that are separated. From this a vibrational excitation of material and

cutting tool ensues, the frequency and amplitude characteristic of which are characteristic for the machining process in question.

[0029]
These microscopic separations lead consequently to a high-frequency machining vibration spectrum from which characteristics concerning the actual machining process can be obtained at a microscopic level.

[0030]
In further applications of the invention such as, for example, welding or component testing, high-frequency characteristic features likewise occur in the vibration spectrum.

[0031]
The registered vibration spectrum preferably undergoes a frequency-time analysis. By means of the frequency-time analysis the registered vibrations can on the one hand be assigned to the process characteristic along the time axis, and on the other hand the vibrations of interest can be separated out from vibrations that are of no interest, such as for example machinery vibrations and spurious vibrations, which occupy other ranges of frequency. The evaluation can therefore concentrate on the range that is characteristic for the application in question.

[0032]
The vibration spectrum is preferably registered with a frequency resolution that corresponds to the microscopic granularity of the material of the component workpiece, and other application-dependent factors as necessary. In a machining process, for example, the machining rate must be taken into account as a further factor. Thus, for example, with a machining rate of 3000 m/min a frequency resolution of 50 MHz is necessary in order to be able to register structures of the order of 1 μm in size in terms of associated machining vibrations. Depending upon the microscopic granularity, which can lie above or below the μm range, and the machining rate, higher or lower frequency resolutions ensue. In accordance with the invention the frequency resolution preferably lies at 50 MHz in order to cover all applications, but can also lie in the region of 40 MHz, 30 MHz, 20 MHz, or 10 MHz.

[0033]

The vibration spectrum can be registered with the coordinates of frequency f, time t, and amplitude A. This registering is suitable for numerical analysis in the computer, wherein the coordinates can also be functions a(f), b(t) and/or c(A) of the frequency f, time t, and/or amplitude A, or a(f, t, A), b(f, t, A) and/or c(f, t, A), such that a three-dimensional array is stored with a given functional dependence on f, t, A, for example (lf, mt, nA^X), where l, m, n, x can be any numbers. For purposes of illustration and/or manual analysis the vibration spectrum can be graphically represented with the three coordinates. Here a three-dimensional representation can be selected in which the frequency and the time define one plane and a height characteristic is defined by the amplitude (or a function thereof). Such a graphical representation eases the recognition of the vibrations that are relevant to the assessment, e.g. by means of separation along the time axis these can be associated with the processing sequence, and can be separated out from machinery vibrations and other spurious vibrations on the frequency axis.

[0034]

For purposes of registering the vibrations a sound sensor, in particular a piezo-sound sensor, is preferably used. Such sound sensors can process the inventively necessary high frequencies, have a large frequency bandwidth, can be manufactured cost effectively, and do not require maintenance.

[0035]

The sensor, in particular the sound sensor, which can be arranged on the component, workpiece or tool, or on a component that is coupled in terms of vibration with the component, workpiece and/or tool, is calibrated after it has been installed and preferably also periodically thereafter, or before each time it is used. By this means a consistently high precision of measurement is ensured. In particular a calibration is advisable if the sensor is fitted to a new workpiece, or for purposes of maintenance must be removed and refitted, since as a result of the refitting another form of coupling characteristic can be introduced. For purposes of calibration in accordance with the invention a particular electrical impulse impinges upon the sound sensor such that the latter emits a sound signal. Subsequently the echo of the sound signal is registered and compared with a design echo. By this means the quality of the coupling of the sound sensor with the workpiece, or cutting tool, or component, can be determined, and taken into account in the measurements.

[0036]
The evaluation preferably takes place in real time. By this means the necessity of storing data is removed. Storage of data can be advisable in the case of safety-relevant components, as evidence of freedom from faults, or as evidence of a fault. The data can be stored in full for the whole treatment process, or the whole duration of the monitoring of a workpiece or component, or can be stored only in the form of extracts for periods of time in which interesting features have been detected.

[0037]
A further aspect of the invention concerns the transformation of the vibration spectrum, or of an interesting range of frequencies from the latter, into an audible sound spectrum by means of a suitable, e.g. linear, function or figure. This enables an acoustic observation and evaluation by a person. The acoustic observation is advisedly executed as a supplement to the multi-dimensional evaluation, but can also replace the latter.

[0038]
In a particularly advisable form of embodiment typical patterns in the vibration spectrum are detected for damage. Here, inter alia, a simplification of the evaluation can ensue that is limited to fault detection.

[0039]
The invention also enables faults to be detected that are not directly related to the processing of a workpiece. For example, tension cracks brought about as a result of temperature fluctuations can be detected, as can in general damage as a result of external influences.

[0040]
Furthermore excessive load cracks and/or fatigue cracks can be detected. This is particularly advantageous when testing a component or when observing a component in operation, e.g. when monitoring a wheel of a railway wagon.

[0041]
The invention thereby creates methods and devices that enable automated monitoring, quality assurance and testing of components, workpieces and treatment processes.

[0042]
Further features and configurations of the invention ensue from the following description with reference to the attached figures.

DESCRIPTION OF FIGURES

[0043]

Fig. 1	illustrates schematically a device for the evaluation of machining processes.

Figs. 2 and 3 show crystallite in a steel structure.

Fig. 4	illustrates a three-dimensional graphical representation of a vibration spectrum.
Fig. 5	illustrates a detail from Fig. 4 in a two-dimensional representation.
Fig. 6	is a section through Fig. 4 parallel to the f-axis.
Figs. 7 and 8	show a projection of the total registered frequency range of Fig. 1 onto the time axis for various tools.

DESCRIPTION OF THE FORMS OF EMBODIMENT

[0044]
The invention is firstly described in what follows in terms of an example of embodiment of a machining process.

[0045]
The device 1 represented in Fig. 1 for the execution of a vibration analysis, here for the purpose of evaluating a machining process, comprises a sensor 2 for the registering of vibrations, which, for example, is arranged on a cutting tool 3 of a machine tool 4, which cutting tool can machine a workpiece 5. The sensor 2 is connected with an evaluation device 6, e.g. a computer. In other configurations

of the invention the workpiece is processed in another manner, e.g. it is welded, formed, joined and/or separated, or a component is tested, or observed during its use in the installed state.

[0046]
The sensor 2 is preferably a structure-borne sound sensor, e.g. a piezo-sensor, and preferably can not only register structure-borne sound signals, but can also transmit them. The transmission of body sound signals is in particular advisable for the testing of components, since the latter can be set into vibration in this manner. Other types of sensors can likewise be used, as long as they can register vibrations in the frequency range of interest, e.g. motion sensors.

[0047]
The sensor 2 is either coupled with the cutting tool 3, as represented in the example, or with the machine tool 4, or with the workpiece 5, or with a part that is vibration-coupled with the latter such that it can register vibrations of the workpiece 5 and/or the cutting tool 3. In the simplest case the sensor is securely screwed down.

[0048]
The machine tool 4, e.g. a milling machine, executes a machining process on the workpiece 5, e.g. a block of steel, with the cutting tool 3, e.g. a milling cutter, in particular in an automated manner, so as to form a gear wheel, for example, from the block of steel.

[0049]
During the machining process vibrations occur on the workpiece 5 and the cutting tool 3, and these are registered by the sensor 2. For this purpose the sensor 2 is designed such that it can register frequencies between a lower limit and an upper limit. Ideally the lower limit is 0 and the upper limit is ∞, so that the whole spectrum of interest can be registered. In practice an upper limit of at least 50 MHz, preferably of at least 100 MHz, is advisable. Frequencies below 90 kHz or 40 kHz are in practice preferably damped or cut out, since they do not contain any useful information, so that an appropriate lower limit is advisable, but can lie at 200 kHz, 500 kHz, or 1 MHz.

[0050]

The actual frequency range of the sensor 2 should be selected on the basis of the material that is being machined and the machining rate. Figs. 2 and 3 show typical crystallite in a steel structure. It can be seen that the grain sizes vary in size, and in fact as a function of the cooling process and the alloy components. If the granularity of the material is, e.g., 1 µm, and the machining rate is 3000 m/min, the upper limit should be at least 50 MHz in order to be able to register the machining vibrations that are of interest. With a machining rate of 400 m/min and an average grain size of 1 µm a minimum resolution of 6.66 MHz ensues. Since however the cutting tool tip (e.g. 1 mm) is very large in comparison to the crystallites (e.g. 1 µm) it always registers very many (e.g. 1000) crystallites at the same time, and in fact slightly displaced by fractions of the grain size; a significantly higher frequency resolution than the minimum resolution is therefore advisable in order to register all the frequency information of interest concerning the machining process.

[0051]

The vibrations registered by the sensor 2 during the machining of the workpiece 5 are evaluated multi-dimensionally. For this purpose the vibration spectrum that is registered can be temporarily stored in the evaluation device 6, which is preferably a computer with an appropriate interface and suitable storage media.

[0052]

In the evaluation device 6 a frequency-time analysis can be undertaken in such a manner that the vibration spectrum is graphically represented and/or numerically analysed while registering is still in progress, or afterwards.

[0053]

As illustrated in Fig. 4, a representation can take a three-dimensional form with the coordinates of time, frequency and amplitude (or maximum amplitude, or intensity, or similar), or as illustrated in Fig. 5, can take a two-dimensional form, wherein height lines render the amplitude visible. In Fig. 5 on the left-hand side the drive shaft can be seen at low frequencies, on the right-hand side are located high-frequency disturbances, and in between can be seen the successive intermeshing of two gears on a motor vehicle transmission shaft. A section through time t is represented in Fig. 6, which shows a typical frequency spectrum.

[0054]
Patterns can be recognised, in particular the islands in Fig. 5, which are characteristic of the process in question. Such patterns also ensue in the event of faults. By means of pattern recognition process steps can therefore be detected and assessed, in that e.g. a measure for the deviation from a pattern is determined, and faults are also detected and identified (drill fracture, no tool present, etc.), in any event deviations from standard behaviour can be detected while processing is still in progress.

[0055]
The evaluation can be undertaken on the basis of Figs. 4, 5 or 6, which are compared with comparative data or empirical values, and from these characteristic features concerning the machining process can be derived. For this purpose patterns from a pattern database can be used. The patterns can be characteristic areas that are stored in a pattern database or functionally described, whose presence in the registered vibration spectrum is to be determined.

[0056]
Figs. 7 and 8 show a projection of the total frequency range registered in Fig. 1 onto the time axis, so that a two-dimensional image is formed. These take the form of records of two turning processes on a steel component, one following directly on the other. Fig. 7 shows the emission when a worn cutting tool is deployed, while Fig. 8 shows the emission after a new cutting tool has been installed. Fig. 8 is visibly smoother and could be used as a reference for the particular turning process, whereby differences from this can be used to assess the cutting tool and/or the workpiece. Here in an automated evaluation of the three-dimensional datasets registered an appropriate reference envelope can be laid around the recorded landscape. Differences, average values, scatter values, etc. could be used as measures for the quality of the process, of the cutting tool, etc.

[0057]
Here the vibration spectrum depends not only on the cutting tool and workpiece, but also on machining rate, the machine tool, consumables (e.g. cooling oil), etc. The vibration spectrum can therefore also deliver information concerning the machine tool or the consumables, etc. Thus the vibration spectrum is possibly modulated by the vibrations of the machine tool, e.g. at 200 Hz.

[0058]
The sensor 2 will have a non-linear frequency response, which is a function of the total system of machine tool, cutting tool, and workpiece. The frequency response is individual for each sensor, and moreover is also dependent on the torque applied when fitted, system resonances, machinery noise, etc. A calibration, in particular periodic calibration during the measurements, is therefore advisable. The calibration can be undertaken in that the sensor 2 transmits an impulse and the impulse response is evaluated.

[0059]
In what follows crack detection is described as an example of embodiment.

[0060]
Crack detection when components such as, for example, wheels, are under load, is made possible with a high level of reliability by the broadband real-time monitoring of structure-borne sound signals.

[0061]
Frequency monitoring and detection enables selective filtering of normal operation noises and component damage occurring spontaneously as a result of excessive load cracks or fatigue cracks in the structure.

[0062]
Each structural separation emits a structure-borne sound emission in the form of an impulse, which can be distinguished from the normal process noises.

[0063]
Real-time monitoring, preferably of the total frequency characteristic over time, enables alterations in the process characteristic to be detected and intervention in a regulatory manner into such fluctuations, so that any damage that might occur can be avoided in a preventative manner.

[0064]
In facilities for the specific causation of damage such as, for example, test stands, the progress of a standard form of damage characteristic can be observed. In this manner it is possible not only to assess the size of the damage after the event, but also to assess the time-wise characteristic of damage formation and also the quantitative build-up as damage develops.

[0065]
By comparison of the registered vibration spectrum with stored damage patterns and standard patterns it is possible to react very flexibly to any damage occurring to a component, or to process drift, even if ranges of frequency are displaced or altered, or new signals, previously unknown, are registered.

[0066]
In the case of frequency separation or frequency filtering that is fixed from the outset such flexible reaction and detection is not possible.

[0067]
The invention can also be applied to welding processes, in particular laser welding.

[0068]
In the case of material treatment with a laser the material is heated and as a result the stresses in the structure are altered. Each such stress alteration generates a pressure wave that propagates through the material. These pressure fluctuations as a consequence of thermal deformation by laser energy can be registered with a structure-borne sound sensor and evaluated in accordance with the invention.

[0069]
At the present time optical systems are deployed for the monitoring of a laser process; these measure the light reflected from the point of impingement and from the spectrum and/or the intensity attempt to derive how the actual laser process is absorbed by the material. Satisfactory results are not always achievable in this manner, since a plurality of materials are to be connected with one another and the process of full penetration welding, that is to say, whether the laser energy also brings about the necessary melting and thermal penetration

of all components, cannot be checked by means of laser emission reflected from the surface.

[0070]
In accordance with the invention structure-borne sound sensors on the components or workpieces can be used to register whether stress fluctuations arise as a result of thermal heating in the components and the stress fluctuations can be analysed for an assessment of the welding process.

[0071]
The energy absorption as a result of the laser light generates temperature fluctuations in the structure and thus varying pressure stresses, pressure waves and frequencies; these allow conclusions to be drawn concerning the type of thermal modifications to the structure. Thus it is possible to map the welding energy and/or the energy absorbed by the material. In particular, welding faults such as a failure to weld fully through a plurality of components to be joined together, the occurrence of holes as a result of excessive transfer of energy, or the absence of the laser beam, can be detected by the inventive multi-dimensional evaluation of the vibration spectrum.

[0072]
Here the vibration sensor, or in particular sound sensor, if necessary a plurality of sound sensors, can be vibration-coupled to the workpieces by means of a device. The one or more sensors can also be placed in fixtures, which, in the event of stressing of the components or workpieces, come into vibration-coupling contact with the components or workpieces.

[0073]
In accordance with the invention in-process monitoring of a process, in particular a laser welding process, is enabled in which no further measures for the monitoring or evaluation of quality are necessary.

[0074]
The invention is also suitable for the observation of a forming process.

[0075]

In every solid body forming process stresses are introduced into the component or released. These alterations in forces lead to pressure waves that propagate through the component and the tool.

[0076]

The frequencies of these pressure waves depend on the dynamics of the forming process, on the velocity with which force is applied, and also on the structure of the material.

[0077]

In general very high frequencies can occur. Analysis of the sound emissions in frequency and time enables a precise description of the forming process and forms a kind of “fingerprint” of each particular forming process. Here variations as a result of varying material properties and process sequences are possible.

[0078]

The inventive method can be applied both to cold forming and also to warm or hot forming. Faults such as, for example, damaged, broken, or missing forming tools can be detected. Varying component strengths during forming, the absence of consumables such as anti-friction agents/lubricants, or alteration of their properties, during hot forming in particular the variations in temperature, can be detected. Even low temperature differences of 1°C can lead to significant alterations in the forming forces and thus to altered properties in the forming dynamics and the pressure wave emissions.

[0079]

If the component cools down during the forming process while the vibrations are being registered, the relaxation, cooling, and shrinkage processes can also be observed and evaluated, as can the structural conversion processes in the material, and a statement can be made concerning the cooling process.

[0080]

This is true both for vibrations, in particular structure-borne sound emissions, which stem from the structural conversion itself, and also for emissions as a result of forces between component and tool, which take place during any alterations in volume.

[0081]
In a quite general sense it is evident that the invention enables in particular the automated observation and evaluation of nearly all treatment processes on the basis of the vibration spectra occurring during the process, including any cooling phase, or similar, which, as described, have characteristic features for standard behaviour and any deviations therefrom. In addition to the above-described examples of chip removal, welding-based and forming processes the invention can also be applied to joining and separating processes.

[0082]
In every joining or separating process various elements interact with one another. During the movement the surfaces rub against one another, material parts are abraded, separated, forces in any form can be introduced. Each of these activities generates pressure waves that propagate through the components that are involved, and that are characteristic for the joining or separating process in question and can be standardised into types.

[0083]
Consequently it is possible to quantify and qualify the joining and separating processes in terms of various properties, that is to say, to define and detect characteristic features.

[0084]
For example, when pressing a shaft into a bush, both of which are produced with tolerances, the sound emission pressure waves provide a measure for the insertion forces. In the event of too much interference between the components, or poor design of tolerances, a very strong sound signal is produced, which can provide evidence of a fault in the pressing operation. With the inventive multi-dimensional evaluation of the registered vibration spectrum these faults can be detected, e.g. by means of comparison with design patterns. Similarly differing surface properties such as, for example, surface roughnesses that are too high, or alterations in material, can be detected, since these have characteristic properties in the vibration spectrum.

[0085]
A screwed joint does not essentially represent anything other than that already described. Here too surfaces are pushed and pressed against one another and the torque applied, together with the friction properties, generates sound

emissions that can be standardised into types, which in turn can be used in the qualification of the screwed joint.

[0086]
The above comments can also be applied to separating processes such as, for example, the driving out of mandrels from bushes, ejection processes, the release of screwed joints, cutting processes, etc.

[0087]
Here in a quite general sense the treatment process is only concluded when alterations to the component or workpiece no longer occur. That is to say, for example, during forming or joining or welding etc., the vibration spectrum can thus be analysed over a longer time period so as to determine stresses occurring, for example, in the event of temperature variations, which in some circumstances can lead to damage to the components, even after the immediate effect on the component or workpiece has concluded.

PATENTKRAV

1. Fremgangsmåde til vibrationsanalyse, hvor vibrationer, som forekommer under anvendelse af en komponent, under afprøvning af en komponent og/eller under bearbejdning af et arbejdsemne (5) ved spåntagning, svejsning, formning, forbindelse og/eller adskillelse, registreres og evalueres, **kendetegnet ved, at** vibrationsspekteret registreres på forskellige tidspunkter eller (kvasi-)kontinuerligt for generering af tredimensionelle data baseret på tid, på vibrations- eller lydfrekvens, og på vibrations- og/eller lydamplitude, hvor de tredimensionelle data underkastes en tredimensionel evaluering, hvor den tredimensionelle evaluering omfatter en sammenligning af de tredimensionelle data med tredimensionelle referencedata for bestemmelse af afvigelser imellem de tredimensionelle data og de tredimensionelle referencedata.

2. Fremgangsmåde ifølge krav 1, hvor vibrationsspekteret underkastes en frekvens-tids-analyse.

3. Fremgangsmåde ifølge krav 1 eller 2, hvor evalueringen udføres automatisk på basis af mønstergenkendelse, hvor mønstergenkendelsen, i et vibrationsspektrum registreret over en tidsperiode, kan søge efter mønstre, som er lagrede eller definerede i en mønsterdatabase.

4. Fremgangsmåde ifølge ethvert af kravene 1-3, hvor en indhylning af vibrationsspekteret dannes og sammenlignes med en sammenligningsindhylning.

5. Fremgangsmåde ifølge ethvert af kravene 1-4, hvor vibrationsspekteret registreres og/eller evalueres under anvendelse af højfrekvens og/eller bredbånd.

6. Fremgangsmåde ifølge ethvert af kravene 1-5, hvor vibrationsspekteret, i tilfælde af bearbejdning ved spåntagning, registreres med en frekvensopløsning

svarende til den mikroskopiske kornstørrelse af materialet for det bearbejdede arbejdsemne (5) og den spåntagne bearbejdningshastighed.

7. Fremgangsmåde ifølge ethvert af kravene 1-6, hvor vibrationsspekteret er repræsenteret grafisk og med de variable frekvens, tid, amplitude eller en funktion deraf; og/eller hvor en lydføler (2) anvendes til at optage vibrationsspekteret, hvor

hvor lydføleren (2) fortrinsvis er kalibreret, hvor, før målingen, et lydsignal udsendes via lydføleren (2), ekkoet detekteres og sammenlignes med en indstillet værdi for ekkoet.

8. Fremgangsmåde ifølge ethvert af kravene 1 -7, hvor evalueringen i det væsentlige finder sted i sand tid.

9. Fremgangsmåde ifølge ethvert af kravene 1-8, hvor det registrerede vibrationsspektrum transformeres til det hørbare område for en akustisk evaluering af en bruger.

10. Fremgangsmåde ifølge ethvert af kravene 1-9, hvor typiske mønstre for skader identificeres i vibrationsspekteret, især overbelastning og/eller træthedsrevner.

11. Indretning (1) til udøvelse af en vibrationsanalyse ifølge ethvert af kravene 1-10, hvor indretningen kan forbindes med en føler (2) til registrering af et vibrationsspektrum, som forekommer under brugen af en komponent, under afprøvningen af en komponent og/eller bearbejdningen af et arbejdsemne (5) ved spåntagning, svejsning, formning, forbindelse og/eller adskillelse eller lignende, og omfatter en evalueringsindretning (6) til tredimensionel evaluering af det tredimensionelle vibrationsspektrum, som er registreret på forskellige tidspunkter eller (kvasi-)kontinuerligt, ved sammenligning med tredimensionelle referencedata, for bestemmelse af afvigelser.

12. Indretning ifølge krav 11, hvor evalueringsindretningen (6) er indrettet til at danne en indhylning for vibrationsspekteret og til sammenligning med en sammenligningsindhylning.

13. Fremgangsmåde ifølge krav 11 eller 12, hvor en højfrekvensføler er tilvejebragt til at registrere et strukturbåret lydspektrum; og/eller

hvor mønsterdatabasen er tilvejebragt med multidimensionelle vibrations-mønstre.

14. Mønsterdatabase til en indretning ifølge ethvert af kravene 11-13, omfattende multidimensionelle vibrationsmønstre, som er karakteristiske for egenskaber i områderne for vibrationsspektre, som forekommer under anvendelsen af en komponent, under afprøvningen af en komponent og/eller under bearbejdningen af et arbejdsemne (5) ved spåntagning, svejsning, formning, forbindelse og/eller adskillelse eller lignende.

15. Anvendelse af en mønsterdatabase ifølge krav 14, til en observation af en komponent under drift, afprøvning af en komponent og/eller en observation af mekanisk bearbejdning af et arbejdsemne (5) ved spåntagning, svejsning, formning, forbindelse og/eller adskillelse eller lignende.

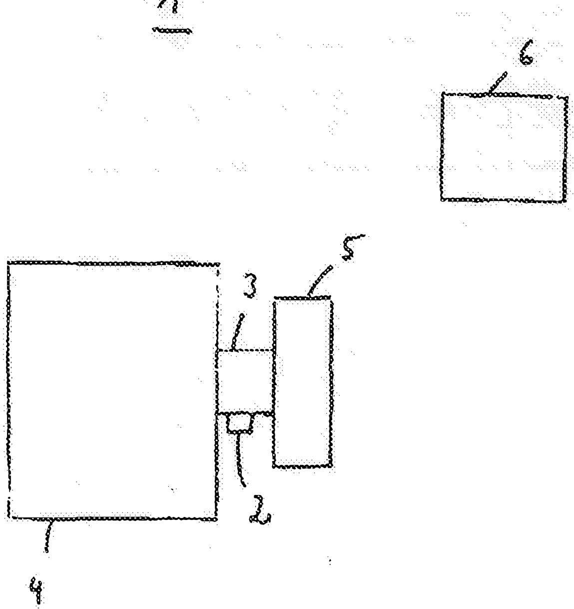

Fig. 1

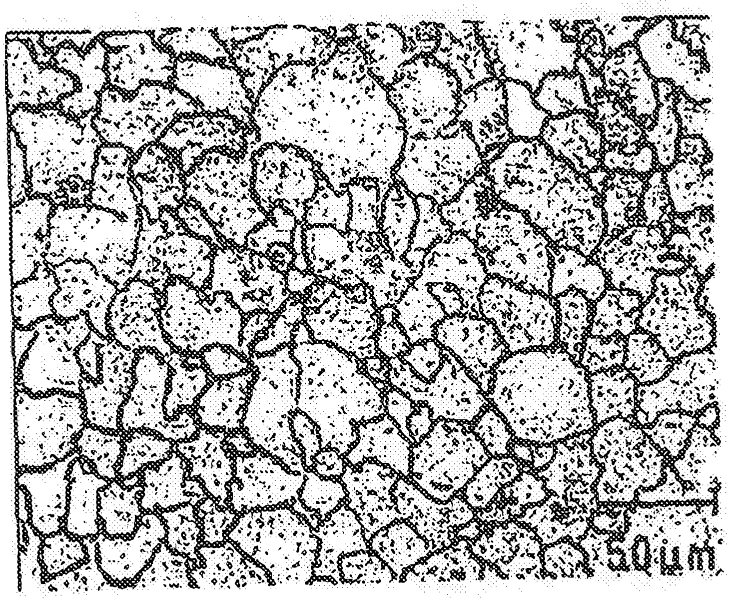

Fig. 2

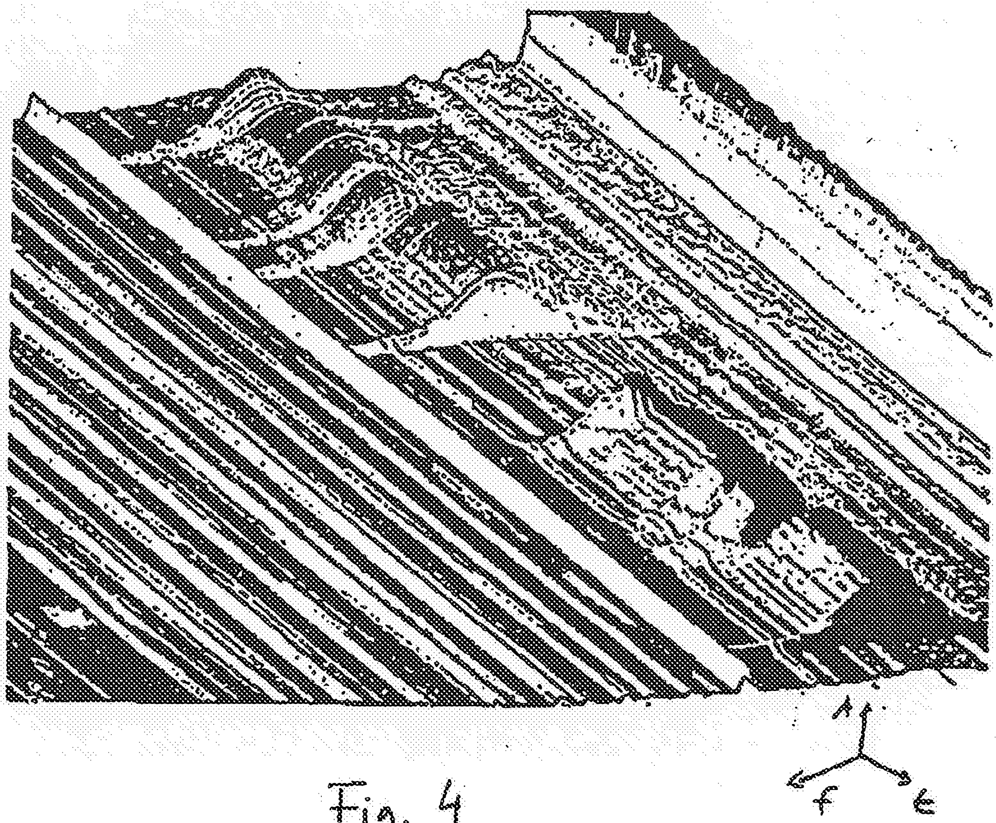

Fig. 4

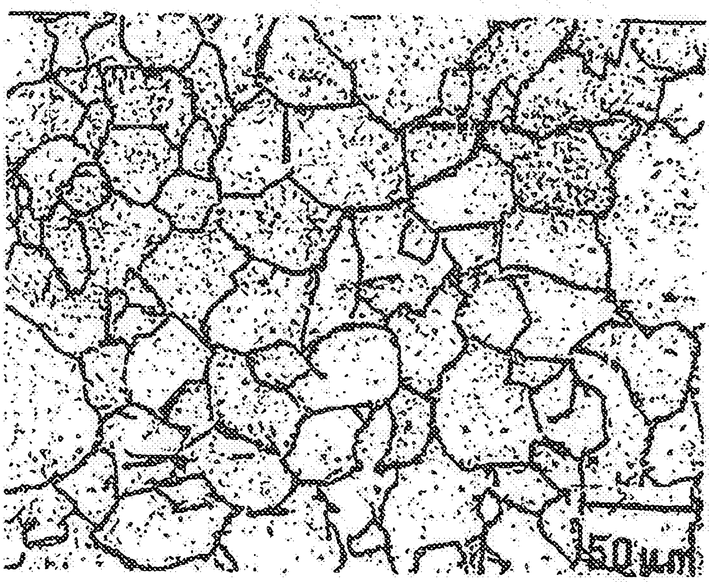

Fig. 3

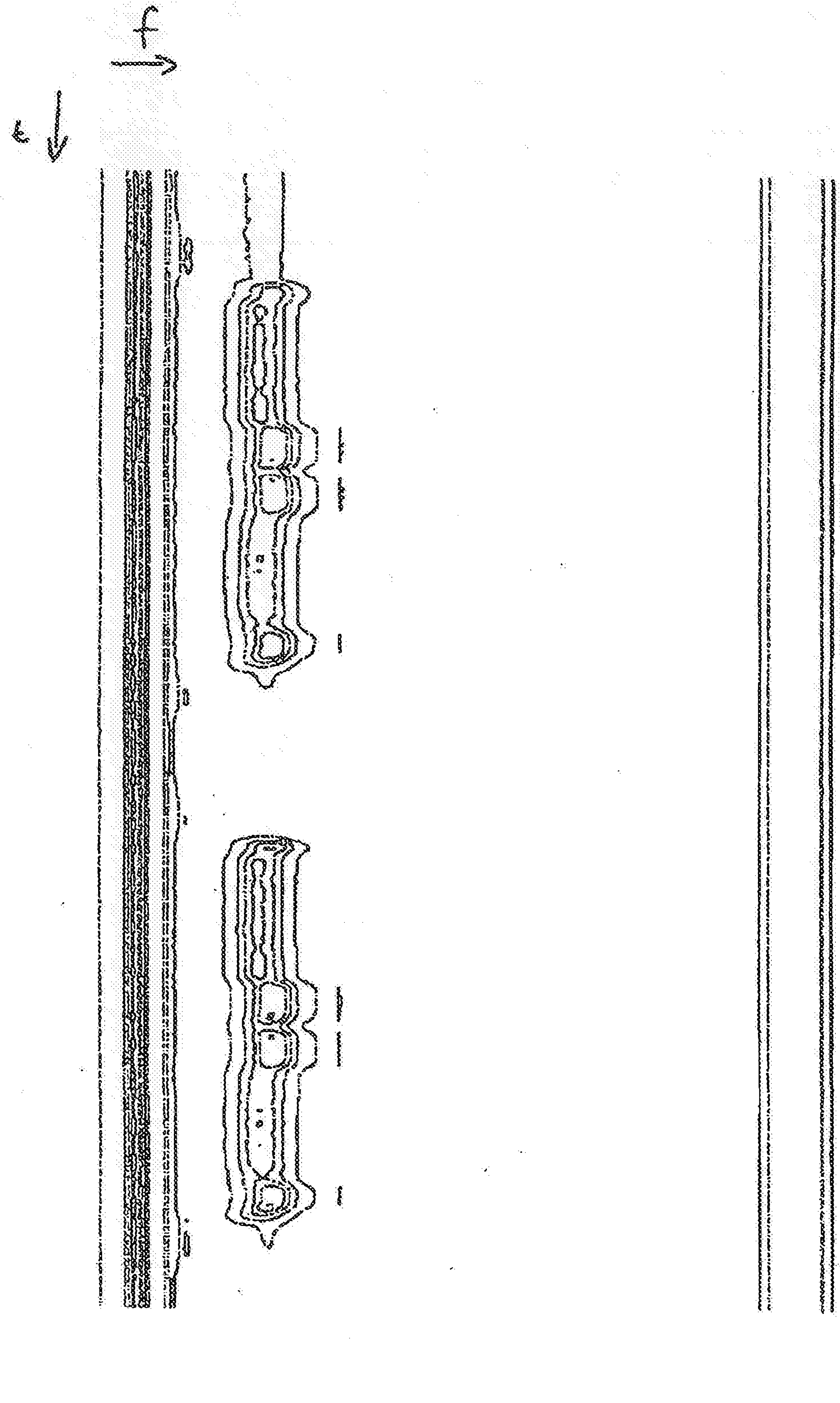

Fig. 5

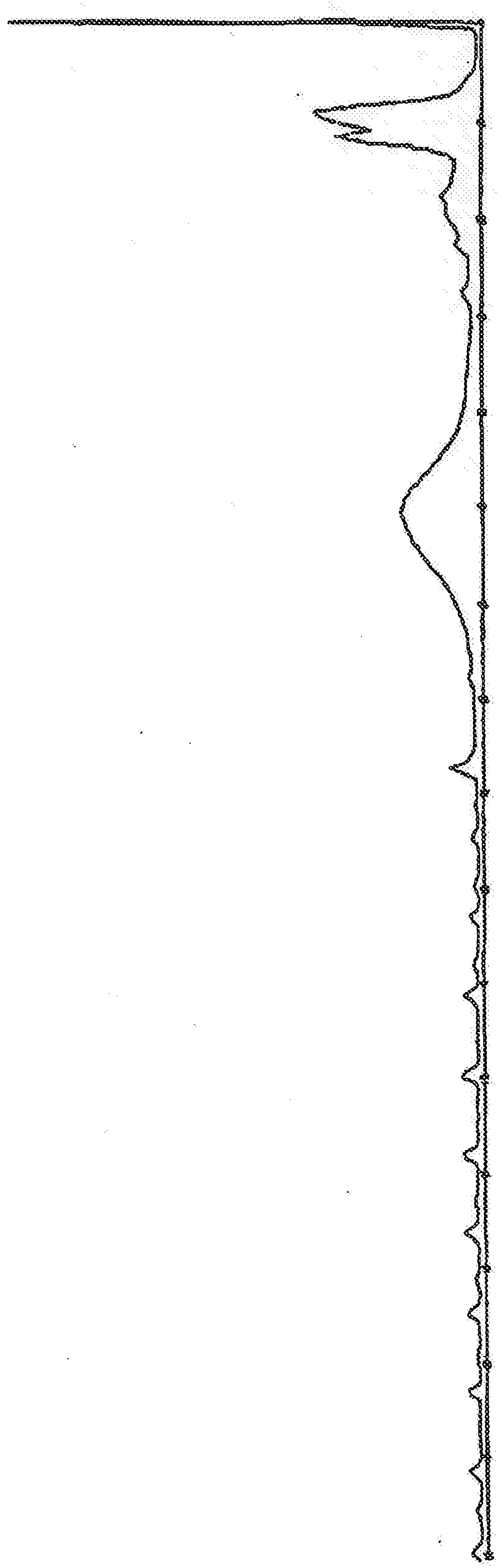

Fig. 6

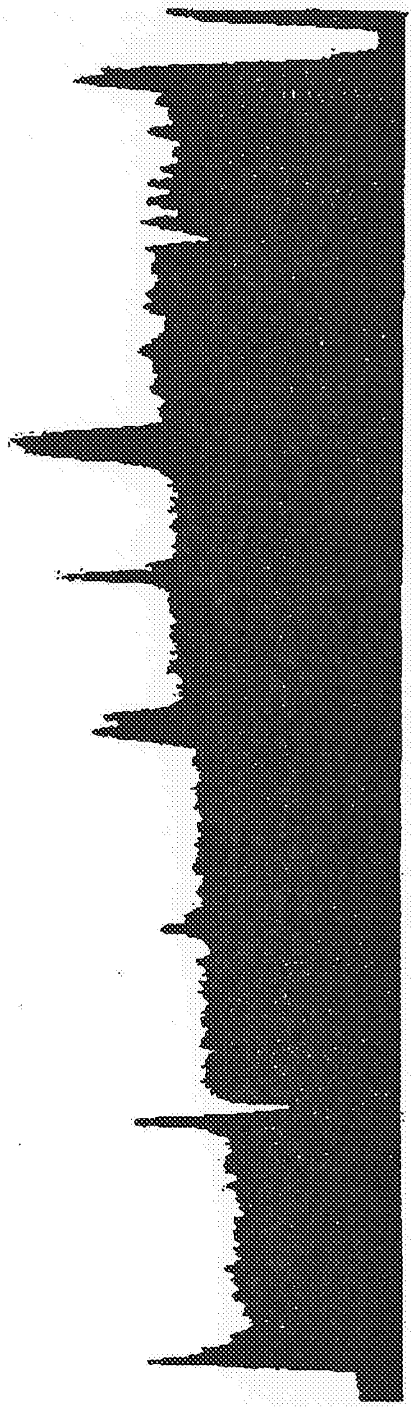

Fig. 7

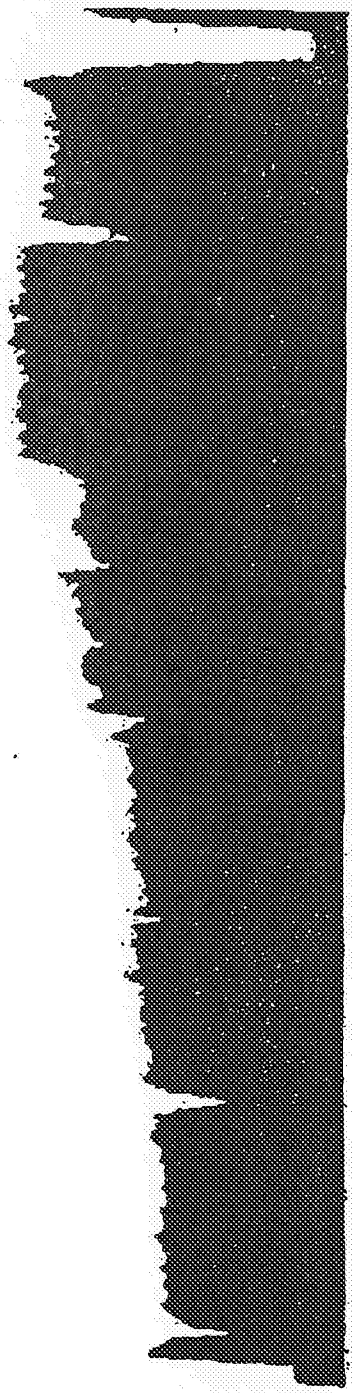

Fig. 8