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Patentability of Computer Inventions

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PATENTABILITY OF COMPUTER IMPLEMENTED INVENTIONS

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ABSTRACT

The issue of patentability of computer implemented inventions has been before the courts in the US for over twenty years. Despite all of the precedent it remains difficult to know which inventions containing mathematical algorithms are patentable subject matter until after an application has been submitted to and examined by the US Patent and Trademark Office. This work seeks to analyze and synthesize cases decided by the US Supreme Court, the Court of Customs and Patent Appeals and the Court of Appeals for the Federal Circuit to better understand what the standards of patentability are. In addition, a case study is presented in which an application is rejected as nonstatutory subject matter. The prosecution history is presented, demonstrating arguments used to overcome the rejection.

PATENTABILITY OF COMPUTER IMPLEMENTED INVENTIONS

Introduction

This thesis will examine the treatment of computer implemented inventions by the United States patent system. The perspective of the Federal Court system as well as that of the United States Patent and Trademark Office will be included. A special emphasis will be placed on control systems and signal processing inventions.

The patent system of the United States was established "to promote the progress of ...the useful arts." The statute that provides the basis for the patent system is Title 35 of the United States Code (hereafter 35 U.S.C.). As explained in 35 U.S.C. 154, a patent gives an inventor the right to exclude others from making, using or selling his or her invention in the United States throughout the term of the patent.

Modern scientific research is highly dependent on electronic computing, provided by mainframes, workstations, personal computers, even pocket calculators. Thus, it is not surprising that a great deal of effort is given towards improving methods and devices for electronic computing. In addition, many improvements in old processes are achieved through computing methods. Breakthroughs in computer-based signal processing have helped to improve medical science, petroleum prospecting, and materials evaluation, to name only a few. Electronic control systems are at least partially responsible for nearly every modern production facility. It is obvious that electronic inventions are important to industry; what is less obvious is the manner in which these inventions are treated by the patent system. A series of decisions has been made over the last 25 years by several different authorities that attempt to define the role of the computing inventions in the patent system and the role of the patent system in computing inventions. This work seeks to analyze these decisions and synthesize them to better understand the current state of U.S. patent law and to determine where the law is headed in the area of computing inventions.

In determining patentablilty of a new invention there are three statutory requirements that must be met as set out in 35 U.S.C. sections 101, 102, and 103. The first refers to "utility and patentable subject matter", the second to "novelty" and the third to "nonobviousness." In his opinion in *In re Bergy*, Judge Rich characterizes these three sections as representing three doors to be opened on the path to patentability.[1] This thesis concentrates on the first door, §101, as it pertains to patentable subject matter. More specifically §101 will be examined to see how it is interpreted pertaining to mathematical algorithms and computer implemented inventions.

Judge Rich writes that the three doors should not be confused and that the analysis under one section should not be combined with the analysis under another. It is the author's contention that this mixing has occurred and that this is part of the problem with the case law in this area. As we shall see in our discussion of the cases below, the idea that the application of a mathematical algorithm is the only novel step in a process invention often leads to a rejection of claims to that invention based on §101. However, novelty is properly the subject of the §102 inquiry. Unfortunately, the courts can only

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[1] *In re Bergy*, 201 USPQ 352 (CCPA, 1979).

review those issues which have been presented on appeal, so if an examiner produces a rejection based on §101 that is the issue on which the court will decide. It may better serve public policy to concentrate on the "nonobviousness" requirements under §103 than subject matter under §101. One worry is that a patent on a combination of a known process with a known mathematical algorithm would constitute taking something from the public domain, however this situation should be prevented by proper use of the obviousness analysis. If both the process and the algorithm are known and the application of the algorithm to the process solves a known and understood process then the combination would be obvious. If, on the other hand, the two are combined in a way which is not obvious then an issued patent would not take anything away from the public.

The issue with respect to patentability of computer implemented inventions and mathematical algorithms hinges on the interpretation of §101 and in particular, the word "process." Section 101, titled "Inventions patentable" states, "Whoever invents or discovers any new and useful *process*, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent therefor, subject to the conditions and requirements of this title "[emphasis added].[2] The issue lies in what is meant by "process" in this context and how we may differentiate between a patentable process and one that is not.

Within the past year, cases have been decided in the Federal Circuit that radically alter the way in which these types of inventions are prosecuted in the United States Patent and Trademark Office (PTO). These cases, along with their forerunners in the United

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[2] 35 U.S.C. 101.

States Supreme Court, the Court of Customs and Patent Appeals (CCPA)and the Court of Appeals for the Federal Circuit (CAFC) which replaced the CCPA, will be discussed and analyzed. In addition, an example of the prosecution of a computer implemented invention will be included to illustrate current practice in this evolving area. This case study concerns a signal processing invention from NASA's Langley Research Center in Hampton, VA. The author participated in the prosecution of the patent application.

Chapter I: United States Court Cases

One would like to trace the history of computer implemented inventions from its beginning; however, it is not always possible to locate the true beginning of a series of events. In law especially, reference is made to prior cases at every step. Even cases considered to be eponymous cite those that have come before them. Here, however, we are forced to begin consideration at some artificial point in the development of the case law. For our purposes the beginning is taken to be *Gottschalk v. Benson.* According to Merges, this decision was "the first Supreme Court opinion on the patentability of computer software...."[3] Though this is true, it ignores the fact that prior to *Benson*, there were cases concerned with §101 and the principles of these cases helped to shape that decision.

A. Gottschalk v. Benson

Applicant Benson presented as his invention "a method for converting binary-coded decimal (BCD) numerals into pure binary numerals."[4] The question before the court was whether this method constituted a "process" as comprehended by §101. The definition under §100(b) is: "The term 'process' means process, art or method, and includes a new

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[3] Merges, Robert. *Patent Law and Policy*, p46.

[4] *Gottschalk v. Benson*, 175 USPQ 673 (US, 1972), 674.

use of a known process, machine, manufacture, composition of matter, or material."[5] This definition includes the term which it seeks to define, presumably implying that the dictionary and colloquial definitions of the word are applicable. Unfortunately, it is not clear where the line may be drawn between a process that is patentable and one that is not.

The PTO rejected claims 8 and 13 of the application on the grounds that they were directed to unpatentable subject matter. Each of these claims was directed to the method of converting binary coded decimal signals to pure binary signals. The binary conversion method in this case was not limited by the claims to use on any particular apparatus nor for any particular end use, but rather was for use on a "general purpose digital computer of any type."[6] The method, as claimed, involves storage of binary coded decimal signals in a shift register, followed by a series of shifts and additions to produce a pure binary signal. The PTO decision was appealed to the CCPA where it was reversed. Then the Supreme Court granted a writ of certiorari and decided the matter in July, 1972. The opinion of the Court was written by Justice Douglas who characterized the invention in the following way:

> The patent sought is on a method of programming a general purpose digital computer to convert signals from binary coded decimal form into pure binary form. A procedure for solving a given type of mathematical problem is known as an "algorithm." The procedures set forth in the present claims are of that kind; that is to say, they are a generalized formulation for programs to solve mathematical

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[5] 35 U.S.C 100(b).

[6] *Benson*, 674.

> problems of converting one form of numerical representation to another. From the generic formulation, programs may be developed as specific applications.[7]

This definition of algorithm is utilized by succeeding courts and thus is very important to the understanding of computer implemented inventions. A simple example of a purely mathematical algorithm is the calculation of the slope of a straight line. If a line has a segment with endpoints at (x, y) and (x', y') in a Cartesian system then the slope is calculated by the following method: (1) determine the rise, which is equal to (y'-y), (2) determine the run, which is equal to (x'-x), (3) calculate the slope, which is equal to the quotient; rise divided by run.

The court looks back to several earlier decisions in constructing its reasoning. The Supreme Court in *MacKay Co. v. Radio Corp.*, had stated that, "While a scientific truth, or the mathematical expression of it, is not a patentable invention, a novel and useful structure created with the aid of knowledge of scientific truth may be."[8] Additionally relying in part on *Funk Bros. Seed Co. v. Kalo Co.*, the court states that, "Phenomena of nature, though just discovered, mental processes, abstract intellectual concepts are not patentable, as they are the basic tools of scientific and technological work."[9] The court here means that even if one were the first to discover the law of gravity one could not patent that law. However, if an inventor creates a machine that makes use of the law of gravity that machine may be patentable. This is the basic reasoning underlying later

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[7] *Benson*, 674.

[8] *MacKay Co. v. Radio Corp.*, 40 USPQ 199 (US, 1939), 202.

[9] *Benson*, 675, quoting *Funk Bros. Seed Co. v. Kalo Co.*, 76 USPQ 280 (US, 1948).

decisions, and allows consideration of what the patentability question really implies. The concern by the courts is that if one could patent any formula or "the basic tools of scientific and technological work," then the exclusive right provided by a patent would allow a single person to limit progress of the useful arts, contrary to the goal of the patent system.

The court characterizes the invention in *Benson* as very broad. The process is not limited to a particular application, rather it may be applied in "both known and unknown uses,"[10] and could even be performed mentally, without the benefit of any computer. It goes on to rely on *O'Reilly v. Morse* for the reasoning that a process (in *Morse,* the transmission of distinguishable electromagnetic signals) could only be claimed in connection with a description of a particular use which must be a part of the patent application, and not so broadly as to preempt any and every use conceived at some later date.[11]

The court further seeks to differentiate processes such as tanning and dyeing which may be implemented without regard to a specific device. It states that these "are instances, however, where the use of chemical substances or physical acts such as temperature control change articles or materials..., [and the limitations are] sufficiently definite to confine the patent monopoly within rather definite bounds."[12] Later decisions in the §101 area will echo this sentiment in their efforts to define a patentable process.

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[10] *Benson*, 675.

[11] *O'Reilly v. Morse*, 15 How. 62 (US, 1854).

[12] *Benson*, 676.

The court goes on to state that, "Transformation and reduction of an article 'to a different state or thing' is the clue to the patentability of a process claim that does not include particular machines."[13]

The decision does not quite go so far as to say that this is the determinative question for processes that are not tied to a specific machine. It also states directly that the decision does not preclude a patent on any computer program.[14]

As Justice Douglas says "in a nutshell" the decision boils down to the following:

> It is conceded that one may not patent an idea. But in practical effect that would be the result if the formula for converting binary code to pure binary were patented in this case.
>
> The mathematical formula involved here has no substantial practical application except in connection with a digital computer, which means that if the judgment below is affirmed, the patent would wholly pre-empt the mathematical formula and in practical effect would be a patent on the algorithm itself.[15]

Finally, the court asks Congress to take further steps in deciding the direction policy should take in the matter of computer program patents.[16]

B. In re Freeman

The next case which we will examine is the CCPA decision in *In re Freeman*. This

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[13] *Benson*, 676.

[14] *Benson*, 676.

[15] *Benson*, 676.

[16] *Benson*, 677.

case provides the beginning of the test that, until very recently, was used to determine patentability under §101, the *Freeman-Walter-Abele* test. *Freeman* was before the CCPA on appeal from the Board of Appeals of the PTO. In an opinion written by Chief Judge Markey, the board's rejection of claims pertaining to a system for typesetting was reversed.[17]

The examiner had rejected claims 1-10 under 35 U.S.C. 112, first paragraph, as lacking complete disclosure and claims 8-10 further as drawn to nonstatutory subject matter under §100, 101. The board reversed the examiner's rejections but then rejected all of the claims "under the principles of *Gottschalk v. Benson*."[18] The board had determined that the invention in question was merely the use of a known device under the control of a novel program. Since the program only had use in conjunction with a digital computer this would constitute a patent on the algorithm itself. Additionally, those claims drafted to devices in "means for"[19] language were held to be equivalent to method claims and that "[the] applicant shouldn't be allowed to claim indirectly what he cannot claim directly with method language."[20]

After restating the nutshell holding of *Benson*, given above, the court goes on to

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[17] *In re Freeman*, 197 USPQ 464, (CCPA, 1978), 465.

[18] *Freeman*, 468.

[19] 35 U.S.C. 112, ¶6 allows for the use of so-called means for language in claims, "An element in a claim for a combination may be expressed as a means or step for performing a specified function without the recital of structure, material, or acts in support thereof, and such claim shall be construed to cover the corresponding structure, material, or acts described in the specification and equivalents thereof."

[20] *Freeman*, 469.

disagree with its application by the board. It restates the holding that one may not properly look to the "point of novelty" for the determination of statutory subject matter.[21]

Additionally, the court disagrees with the board's broad reading of Freeman's application in stating that "the only novelty resides in a program for a general purpose digital computer."[22] In further analyzing the decision of the board, the court states:

> The fundamental flaw in the board's analysis in this case lies in a superficial treatment of the claims. With no reference to the nature of the algorithm involved, the board merely stated that the coverage sought "in practical effect would be a patent on the algorithm itself." Though the board gave no clear reasons for so concluding, its approach would appear to be that every implementation with a programmed computer equals 'algorithm' in the *Benson* sense. If that rubric be law, every claimed method that can be so implemented would equal nonstatutory subject matter under 35 USC 101. That reasoning sweeps too wide and is without basis in law.[23]

In the *Freeman* case it is the specification rather than the claims[24] that speak to computer

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[21] The court here makes reference to *In re de Castelet*, 195 USPQ 439, 443 (CCPA, 1977); *In re Chatfield*, 191 USPQ 730, 736 (CCPA, 1976), cert. denied, 195 USPQ 465 (US, 1977).

[22] *Freeman*, 470.

[23] *Freeman*, 470.

[24] The claims are that portion of the patent application which outline exactly what invention is to be protected by the patent grant, while the specification is a descriptive portion which serves to make clear the implementation of the invention.

implementation.[25]

It is the court's analysis of the method claims that leads to the creation of the so-called *Freeman* test. The court calls for a two step analysis as follows:

> First, it must be determined whether the claim directly or indirectly recites an "algorithm" in the *Benson* sense of that term, for a claim which fails even to recite an algorithm clearly cannot wholly preempt an algorithm. Second, the claim must be further analyzed to ascertain whether in its entirety it wholly preempts that algorithm.[26]

In this case the court finds that it does not reach the second portion of the test as the method claims "do not recite an algorithm in the *Benson* sense."[27]

Interestingly, the court here decides that it is important to really define what an algorithm is, differentiating between a mathematical algorithm, which we recall from the earlier discussion of *Benson* to be a procedure for solving a particular mathematical problem, and the Webster's definition cited in *In re Chatfield*, as a "step-by-step procedure for solving a problem or accomplishing some end."[28] The point is made here that any process invention would be an algorithm in the second sense and that the court may not interpret the word process "out of the statute."[29]

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[25] *Freeman*, 470.

[26] *Freeman*, 471.

[27] *Freeman*, 471.

[28] *In re Chatfield*, 191 USPQ 730 (CCPA, 1976), 734 n.5.

[29] *Freeman*, 471.

The court additionally sees the need to define ways in which an algorithm may be recited to fulfill the first step of their proposed test. While some claims may go so far as to directly recite a mathematical formula (as we will see in our next case), others will state them less directly in English equivalents of mathematical symbols (as in *Benson*, above). These are the two primary ways that the court envisions an applicant reciting algorithms.

Finally, the court here puts forth the idea that an apparatus claim using "means for" language as allowed under 35 U.S.C. 112 does not save the claim from being analyzed under the proposed test. "Means for" language is basically a way of translating a process claim into an apparatus claim. By changing a claimed process step such as "rotating a widget" into a device, "means for rotating a widget," a machine is claimed instead of a process. The court here is saying that if an apparatus claim is merely restating what would be a nonstatutory process with "means for" accomplishing each step, then the apparatus claim should not be granted.[30]

It may seem that here we are given a simple test to determine patentablility, but unfortunately it is not quite that easy. Both cases we have read use language like "wholly preempt the algorithm" to describe what is an unpatentable claim but neither has satisfactorily set the standard for preemption. The second step of the *Freeman* test continues to be a point of contention and confusion.

C. Parker v. Flook[31]

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[30] *Freeman*, 472.

[31] *Parker v. Flook* was decided by the CCPA prior to their decision in *Freeman*, however, it was then appealed to the Supreme Court. Since the final decision was rendered after the final *Freeman* decision it has been placed here.

Inventor Flook applied for a patent on a method for updating alarm limits. The process involved measuring a process variable, calculating an updated alarm limit value and adjusting the actual alarm limit value. In this case the alarm was used to indicate the end of a process of chemical conversion of hydrocarbons. The examiner rejected his application and was sustained by the Board of Appeals. The CCPA reversed the board's decision on the grounds that the algorithm was not wholly preempted but rather only its use in catalytic conversion of hydrocarbons (as discussed in the application disclosure).[32] The examiner had found that the only novelty was in the formula, and Flook did not challenge that finding. Therefore, that is the issue on which the Supreme Court opinion focuses.

Once again the question turned on whether the applicant had wholly preempted the algorithm. There was no argument as to whether an algorithm was present in the claims in this case because equations were explicitly expressed therein.[33] The applicant argued that only those uses that pertained to petrochemical cracking were covered by his claims, and thus other uses of the formula remained in the public domain. He also argued that some post solution activity, namely the updating of an alarm limit, distinguished his case from *Benson* which had no steps after the conversion of BCD numbers to pure binary numbers.[34]

The post solution activity argument is wholly rejected by the court and this

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[32] *Parker v. Flook*, 198 USPQ 193 (US, 1978), 196.

[33] *Flook*, 200.

[34] *Flook*, 200.

prohibition survives into present day practice. The court states: "The notion that post-solution activity, no matter how conventional or obvious in itself, can transform an unpatentable principle into a patentable process exalts form over substance."[35] As in *Benson,* above, the court is careful to state that simply incorporating a mathematical formula or law of nature will not render a process unpatentable.[36]

The court reasons:

> The chemical processes involved... are well known; as are the practice of monitoring the chemical process variables, the use of alarm limits to trigger alarms, the notion that alarm limit values must be recomputed and readjusted, and the use of "computers for automatic process monitoring-alarming." Respondent's application simply provides a new and presumably better method for calculating alarm limit values. If we assume that that method was also known, as we must under the reasoning in *Morse*, then respondent's claim is, in effect, comparable to a claim that the formula 2r can be usefully applied in determining the circumference of a wheel.[37]

This reasoning would appear to have a flaw in the sentence, "If we assume that that method...." Flook attempted to argue this point and the court almost ignores the argument, neither accepting it nor rejecting it. In a footnote the court declares:

> Whether or not respondent's formula can be characterized as "obvious," his

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[35] *Flook*, 200.

[36] *Flook*, 198-199.

[37] *Flook*, 199.

> process patent rests solely on the claim that his mathematical algorithm, when related to a computer program, will improve the existing process for updating alarm units [sic, presumably "limits"]. Very simply, our holding today is that a claim for an improved method of calculation, even when tied to a specific end use, is unpatentable subject matter under §101.[38]

It seems odd that the lucid explanation of what the court finds to be unpatentable is buried in a footnote in the middle of the decision. To a large extent, the prior characterization of the method as being made up of well known parts recited above is irrelevant in the face of this footnote.

It is interesting to note that the court makes no mention of the *Freeman* decision. In fact, as the *Freeman* test stood at this point there would not have been much purpose to the use of that test. The first step is met as there was no argument over whether an algorithm was recited, and the second step is too poorly developed to offer any guidance. The *Flook* court does not take the opportunity to expand on the second step here and we will have to wait for our next case for such an expansion.

Just as in *Benson*, the court at the end of its opinion asks for Congressional guidance in this new area of law.

The dissenting opinion does mention *Freeman*, and is instructive as it more closely parallels the development of law in the CCPA and its successor the CAFC. The dissent finds that the lower court decision is "wholly in conformity with basic principles of patent

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[38] *Flook*, 199.

law."[39] It sees the issue as "whether a claimed process loses its status of subject matter patentability simply because one step in the process would not be patentable subject matter if considered in isolation."[40] From this perspective it seems that the dissent is agreeing with the *Freeman* court that a "point of novelty" test is inappropriate, despite not using that specific language. The majority does not see this as an issue at all, and never mentions point of novelty, despite using essentially that reasoning.

D. In re Johnson, Parrack and Lunsford

This opinion of the CCPA concerns three related patent applications for methods of noise reduction in a seismic trace, representing sound reflected from underground structure. The applications in question used spatially separated detectors and time-windowing to pick out coherent portions of a seismic trace. The applicants had developed the process for use in prospecting for petroleum.[41] The board had affirmed the examiner's rejection based on §101 stating, "that *Gottschalk v. Benson*, 409 U.S. 63, 175 USPQ 673 (1972), and *In re Christiansen*, 478F. 2d. 1392, 178 USPQ 35 (CCPA, 1973), preclude a patent grant for any 'subject matter which is algorithmic in character.'"[42] *Benson* really says that one cannot hold a patent on the algorithm itself, it does not deny a patent on any matter which is algorithmic in character. We recall from our analysis of *Benson* that the court had specifically stated that their decision did not preclude all computer programs

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[39] *Flook*, 201.

[40] *Flook*, 201.

[41] *In re Johnson, Parrack and Lunsford,* 200 USPQ 199 (CCPA 1979) 202.

[42] *Johnson*, 205.

from patentability. This is the line of reasoning used by the court in *Johnson*.

Recognizing that the board had not yet seen *Flook* when it considered the present applications, the court admits that there was a degree of uncertainty in comprehending the scope of the *Benson* decision. However, the statement, "it is clear after *Flook* that the board's conclusion that patent protection is proscribed for all inventions 'algorithmic in character' is overbroad and erroneous."[43] makes it clear that the court does not agree that any uncertainty exists after *Flook*.

Unlike the Supreme Court in *Flook*, the CCPA does make mention and use of the *Freeman* test showing that the CCPA is willing to adopt that test as a tool for analysis of the §101 issue.[44] In conducting the inquiry under the first step of the *Freeman* test the court finds such words as "computing," "determining," and "cross correlating" to be indirect recitations of "mathematical calculations, formulae, or equations."[45] In the second step analysis, the court characterizes the processes as operating on a seismic trace to produce a new noiseless seismic trace, differentiating these traces from "mere mathematical values."[46] Moreover, the "mathematical operations performed in practicing the method recited in claim 13 are incident to producing a noise-free signal trace from a reference trace, and by no interpretation can claim 13 be construed to be a mere procedure

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[43] *Johnson*, 205.

[44] *Johnson*, 207.

[45] *Johnson*, 208.

[46] *Johnson*, 207-208.

for solving a given type of mathematical problem."[47] Similar reasoning holds for the other claims in issue in each of the three appeals with the key point always that the computing step is merely a step in a larger procedure. *Johnson* is important in that it expands the basis for understanding the *Freeman* test, and specifically it is an example of a signal processing patent, a type that has become more important in recent years. We will examine other signal processing cases later and the case study which ends our present discussion relates to signal processing.

E. In re Bergy, Coats and Malik and In re Chakrabarty

In re Bergy reached its conclusion before the CCPA. Due to a similarity in subject matter, this case had become entangled with *In re Chakrabarty*.[48] Both of these cases were decided by the CCPA in light of the Supreme Court decision in *Flook*, above. It was here that Judge Rich put forth the concept of three doors to patentability.[49]

While this pair of cases does not touch on algorithm patentability it does concentrate on §101. In addition, the *Bergy* opinion gives us a good indication of how we should conduct the analysis of patent applications with respect to the three tests of patentability.

Judge Rich makes it very clear that the three doors outlined in §§101,102, and 103,

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[47] *Johnson*, 209.

[48] The full history is not germane to the present discussion but is available to the reader at 201USPQ 352 (CCPA, 1979), 356-308.

[49] see note 1. In addition, for those unfamiliar with the patent system, Judge Rich sets forth the history, constitutional basis, and current (to 1979) statute as a background to the court's opinion. One could do worse than to start here in the study of patent law.

subject matter, novelty and nonobviousness respectively, are separate and should be kept so. In addition *Flook* is quoted as stating that analysis of §101 must precede analysis of the other two.[50] He continues:

> The person approaching that door [subject matter] is *an inventor*[51], whether his invention is patentable or not. There is always an inventor; being an inventor might be regarded as a preliminary legal requirement, for if he has not invented something, if he comes with something he knows was invented by someone else, he has no right even to approach the door. Thus, section 101 begins with the words "Whoever invents or discovers," and since 1790 the patent statutes have always said substantially that.... What *kind* of an invention of discovery is it? in dealing with the question of kind... "any ...process, machine manufacture, or composition of matter, or any... improvement thereof." If the invention, as the inventor defines it in his claims (pursuant to §112, second paragraph), falls into any one of the named categories, he is allowed to pass through to the second door, which is §102; "novelty and loss of right to patent" is the sign on it. Notwithstanding the words "new and useful" in §101, the invention is not examined under that statute for novelty because that is not the statutory scheme of things or the long-established administrative practice.[52]

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[50] *Bergy*, 360 n. 4.

[51] Prior to the 1952 patent law, "invention" implied nonobviousness, these terms were separated in the new law. Judge Rich tries to make this very clear.

[52] *Bergy*, 360-361.

The direction that is taken here is that the novelty requirement is wholly removed from the subject matter requirement. The opinion goes on make this point in several ways, citing academic legal writings, congressional documents and PTO policy. Judge Rich opines that with small exception the PTO does separate novelty from §101 issues.[53]

F. In re Walter

Our next case is more specific to the problem of computing inventions. *In re Walter* is most important in that it helps to flesh out the two-step test put forth in *Freeman*. As in *Johnson* the applicant has invented a method pertaining to petroleum prospecting using seismic waves.[54] In one type of seismic prospecting a signal having time varying frequency is projected into the earth. The signal bounces off of underground features and the return signals are received by a series of spatially separated transducers. Applicant Walter presented an improved method for cross-correlating the return signals with the input signal to sort out the information being received. The improvement (as recited in the claim) was in splitting the signal into time segments, performing a Fourier transform on successive pairs of segments, repeating these operations on the input signal, and performing a cross-correlation (using the Cooley-Tukey algorithm as modified by Bergland) on the resulting sets of Fourier space vectors. Walter called these correlated signals "partial product signals."[55]

The examiner rejected the claims as being drawn to the mathematical procedure

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[53] *Bergy*, 361.

[54] *In re Walter*, 205 USPQ 397 (CAFC, 1980) 401.

[55] *Walter*, 402-402.

itself. The apparatus claims were not distinguished from the method claims because, "the only mode of practicing [the] invention is disclosed by way of an algorithm for use in a computer program." The board affirmed. The board agreed that method and apparatus claims were indistinguishable, arguing that, "It would be anomalous to grant apparatus claims encompassing any and every 'means for' practicing the method claimed in the method claims if the latter were nonstatutory."[56]

In its further analysis the board characterized the claims in the following way. The preamble was directed to the gathering of data and the succeeding steps consisted of allocating sampled signals to memory locations in a computer and producing an end result, the partial product signals.[57] The board found that the steps were, at the level seen by the computer, mathematical in nature; further that the steps concerning themselves with adjusting data to fit memory locations were mathematical; and, finally that the processing itself was mathematical.[58] Thus, the first step of the *Freeman* test was fulfilled. The board next addressed whether the algorithm was preempted by the claims, finding that it would, as it could only be performed using a computer, fulfilling the second step. *Johnson* was distinguished as producing an improved signal instead of partial product signals.

The applicant argued that the claims were directed not to producing merely a number, but rather to a method "that produces a physical result (the partial product

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[56] *Walter*, 403. This reasoning keeps reappearing throughout our cases, it does seem to be sound as it is a trivial matter for a claims draftsman to translate a method claim into an apparatus claim using means for language.

[57] *Walter*, 403.

[58] *Walter*, 403.

signals) by physical processing of physical signals...described in mathematical terms," and further to an apparatus that performs the method.[59] In addition, Walter argued that the claims were limited to a single, encompassing device and that the method could be performed with multiple devices, therefore others were not prohibited entirely from performing the mathematical algorithm.[60]

The opinion of the court rejects the argument that *Flook* had established a point of novelty test, stating that an improvement invention wherein the improvement lies in the application of a mathematical algorithm to a known process should be statutory subject matter. The court reasons that a different standard for subject matter should not exist for improvement inventions. "There is no evidence that Congress intended a different criterion to apply to improvement inventions to determine whether they are statutory," and the court becomes even more forceful in stating, "We do not read *Flook* as adopting a 'point of novelty' test; as we have shown, such a test flies in the face of Supreme Court precedent reaffirmed in *Flook*, and does violence to the statute."[61] It further is argued that the *Flook* mandate to examine the claim as a whole would be ignored in a point of novelty test since such a test necessarily concentrates on less than the whole.

Next, the court tackles the second step of the *Freeman* test; it is here that *Walter* becomes important in the discussion of what constitutes preemption of an algorithm. The important analysis is to examine "the relationship between the algorithm and the physical

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[59] *Walter*, 403.

[60] *Walter*, 404.

[61] *Walter*, 406.

steps or elements of the claim."[62]

The court finds the second step of the Freeman test inadequate and so restates it:

> Once a mathematical algorithm has been found, the claim *as a whole* must be further analyzed. If it appears that the mathematical algorithm is implemented in a specific manner to define structural relationships between the physical elements of the claim (in apparatus claims) or to refine or limit claim steps (in process claims), the claim being otherwise statutory, the claim passes muster under §101. If, however the mathematical algorithm is merely presented and solved by the claimed invention, as was the case in Benson and Flook, and is not applied in any manner to physical elements or process steps, no amount of post-solution activity will render the claim statutory; nor is it saved by a preamble merely reciting the field of use of the mathematical algorithm.[63]

This is further clarified by the prohibition against the product being a "pure number," such inventions being "nonstatutory regardless of any post-solution activity which makes it available for use by a person or machine for other purposes," but differentiates *Johnson*'s seismic trace as being a "physical thing" rather than a pure number.[64] Mathematicians and philosophers may take issue with the idea that a series of numbers gleaned from measurements are any more physical than any other series of numbers but this is an issue that the courts leave alone.

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[62] *Walter*, 407.

[63] *Walter*, 407.

[64] *Walter*, 407.

The apparatus claims were not treated separately from the method claims as discussed earlier and the court agrees with the lower authorities' decision not to do so. The court states that the claims are not limited to a unitary device and refuses to read the best mode as presented in the specification as limiting the claims.[65]

The court objects to the board's reasoning with respect to the finding that at low levels the computer operations are mathematical in nature, finding that, "An overall characterization of [data manipulation and memory allocation] operations as mathematical is too broad because in concentrating on the minutiae, it ignores the whole."[66] With respect to the point that the processing itself is mathematical the court agrees with the board. Using the factors outlined above, the court proceeds to analyze the invention. The preambles to the claims are said to "merely set forth the environment in which the improvement operates," while the claim itself does not set forth any corresponding limitation.[67] The preambles lead to a specific end use of the data that has been processed but according to the new test a specific end use is not, in itself, sufficient. The claims are characterized as beginning and ending with the calculation and therefore nonstatutory.[68]

Despite having already reached its conclusion, the court proceeds to justify its decision by going on to find that the partial product signals are nonphysical. They are the result of mathematical modeling, and not a physical signal as was the subject of the

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[65] *Walter*, 408.

[66] *Walter*, 408.

[67] *Walter*, 409.

[68] *Walter*, 409.

invention in *Johnson*.[69] This is a somewhat questionable conclusion, as the signals begin as physical signals just as in *Johnson*, the difference being that in this invention the cross correlation has created a simulation of an impulse signal from a time varying source.

In several of the claims the output of the process is printed onto a tape making it available for reading by an operator. The issue of eye readability of the output is found to be without merit, the court once again stating that it is a trivial matter for a claim draftsman to add such a step. As for two of the claims directed to the method of cross correlation itself, the court finds that they are clearly "outside the bounds of §101."[70]

G. Diamond v. Diehr

This case concerns a control system invention. Applicant Diehr presented an invention relating to a control process for manufacturing cured rubber products. In the production of precision rubber products an uncured rubber is placed, along with curing agents, in a mold under heat and pressure; after some time the rubber is cured and may be unmolded. Factors that affect the proper curing are size and geometry of the article and time, temperature and pressure of the curing. The proper time and temperature are calculated by means of an Arrhenius relationship.[71] The applicant stated that industry "[had] not been able to obtain uniformly accurate cures because the temperature of the molding press could not be precisely measured,"[72] thus the cure time could not be properly

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[69] *Walter*, 409.

[70] *Walter*, 409.

[71] *Diamond v. Diehr*, 209 USPQ 1(US, 1981), 4.

[72] *Diehr*, 4.

calculated. Diehr's innovation was to constantly monitor the temperature inside the mold and further to recalculate the time using the updated temperature information. In addition, Diehr's device controlled the opening of the mold.

The examiner rejected all of the claims on the grounds that they were drawn to nonstatutory subject matter. The examiner argued that the steps concerned with putting rubber into a press, closing the press and opening the press after the cure were "conventional in nature and [not a] basis for patentability."[73] The other steps constituted the computer control of the process and were considered by the examiner to be nonstatutory.

The board agreed with the examiner but the CCPA reversed. The court reasoned that "a claim drawn to subject matter otherwise statutory does not become nonstatutory because a computer is involved."[74] The Supreme Court granted certiorari to further refine the understanding of computer process inventions.

After analyzing the statutory language the court goes on to state that, "...we think that a physical and chemical process for molding precision synthetic rubber products falls within the §101 categories of possible patentable subject matter."[75] The court is not swayed from this stand by the fact that several steps in the process are implemented by a digital computer and utilize a mathematical equation. The court's reasoning, for the most part restates those opinions which we have already examined, defining algorithm as a

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[73] quoted in *Diehr,* 5.

[74] *Diehr*, 5, 6.

[75] *Diehr*, 7.

procedure for solving a particular mathematical problem following the *Benson* court, and recalling the prohibition against the computation of a pure number as in *Flook*. Further, the court recalls that the claims as a whole must be considered, "It is inappropriate to dissect the claims into old and new elements and then to ignore the presence of the old elements in the analysis.... The 'novelty' of any element or steps in a process, or even the process itself, is of no relevance in determining whether the subject matter of a claim falls within the §101 categories of possibly patentable subject matter."[76] It is interesting to note at this point that the court finds the need to discuss, in a footnote, the portion of the *Flook* decision where it assumed that the formulaic portion of the invention was already known.[77] The government read *Flook* to say that if all other elements are old and an algorithm is added that utilizes a law of nature, the invention is nonstatutory and the court rejects this interpretation.[78]

The court goes on to fully reject a point of novelty test of statutory subject matter. It cites the *Bergy* opinion in this regard fully separating the §101 inquiry from the novelty requirement of §102. In addition notes detailing the legislative history of the Patent Act of 1952 are cited to bolster this finding.[79]

In concluding the opinion, the court states, "We view respondents' claims as nothing more than a process for molding rubber products and not as an attempt to patent a

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[76] *Diehr*, 9.

[77] *Flook*, 199.

[78] *Diehr*, 9 n. 12.

[79] *Diehr*, 10.

mathematical formula."[80] Despite the reasonable sounding conclusions, four Justices joined in a dissent that was quite a bit longer than the opinion. The first several pages constitute a history of court decisions about §101. The analysis of why the dissent considers Diehr's invention to be unpatentable essentially boils down to one issue. On one hand, the majority has characterized the invention as a new process for curing rubber, on the other hand, the dissent calls it a, "new method of programming a digital computer in order to calculate - promptly and repeatedly - the correct curing time in a familiar process."[81] After the long history, including the rejection of the point of novelty test, the dissent appears to base its objection on a similar test:

> There is no suggestion that there is anything novel in the instrumentation of the mold, in actuating a timer when the press is closed, or in automatically opening the press when the computed time expires. Nor does the application suggest that Diehr and Lutton have discovered anything about the temperatures in the mold or the amount of curing time that will produce the best cure. What they claim... is a method of updating the original estimated curing time by repetitively recalculating that time pursuant to a well-known mathematical formula in response to variations in temperature within the mold.[82]

This would seem to simply be a restatement of the point of novelty test. The dissent argues that each step is known so the process is not patentable subject matter. This flies

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[80] *Diehr*, 10.

[81] *Diehr*, 19.

[82] *Diehr*, 17-18.

in the face of Judge Rich's admonition not to mix the §101 inquiry with that of novelty under §102.

H. In re Abele and Marshall

The inventors in this case developed an improved method for producing computerized axial tomography (CAT) scans. The improvement in image processing allowed for an image to be produced with smaller exposure to radiation than was previously necessary. This was achieved while simultaneously enabling superior reliability in image production.[83]

The court begins with a description of conventional as well as computed tomography. The new process makes use of a more narrow beam of x-ray radiation than prior art techniques. The narrowed beam is chosen to be only as wide as the region of interest. In contrast, prior art techniques used beams as wide as the entire object being imaged. Narrowing the incident beam allows a reduction in both computing time due to the reduced amount of data, and in radiation doses absorbed by the imaged object (since the object in question is usually a person limiting radiation dose is a desirable result). One drawback is that the reduced amount of data may not be sufficient to remove all artifacts of objects that lie outside the region of interest but in the beam path. Applicant's process allows for the use of a signal processing algorithm to reduce the effect of such artifacts.

The examiner rejected the claims using *Flook* as the basis for rejection:

> Taking each claim as a whole, it is assumed, for analysis purposes only, that any mathematical calculation in the claim is part of the prior art. If what is left is new

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[83] *In re Abele and Marshall*, 214 USPQ 682 (CCPA, 1982), 683.

> and unobvious, then the claim, taken as a whole, protects more than a mathematical calculation and it is deemed statutory. But if the remainder of the claim is not novel nor unobvious, then the claim, taken as a whole, merely seeks to protect the mathematical calculation and, as such, does not comprise statutory subject matter.[84]

Once again we run into a type of "point of novelty" test. It is fairly obvious that the examiner here has made the same mistake that the CCPA has been criticizing all along, i.e., the inquiry as to subject matter is intertwined with the concepts of novelty and nonobviousness. The examiner's analysis under this test called for rejection under §101.

The board formed the same conclusion but based its decision on the *Freeman-Walter* test, stating that the algorithm present did not serve to, "define structural relationships between physical elements... or to refine or limit claim steps in the process claims."[85]

The court concurs that the two step test as introduced in *Freeman* and *Walter* is appropriate for the §101 inquiry, however it feels that the second step requires further refinement. Once again a quick history of the debate is given by the court prior to outlining the new holding. The court in *Abele* finds that the board's analysis under the second step is inadequate for determination of patentability in the case of the gray area that lies between a claim that simply presents and solves a mathematical problem (clearly unpatentable) and one that implements an algorithm to define structural relationships or

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[84] *Abele*, 684.

[85] *Abele*, 685.

refine or limit claim steps (clearly patentable). While this is the specific language as cited above, the court here determines that:

> ... *Walter* should be read as requiring no more than that the algorithm be 'applied in any manner to physical elements or process steps,' provided that its application is circumscribed by more than a field of use limitation or non-essential post-solution activity. Thus if the claim would be 'otherwise statutory' ... without the algorithm, the claim likewise presents statutory subject matter when the algorithm is included.[86]

This 'otherwise statutory' interpretation recalls the reasoning employed by the Supreme Court in the *Diehr* decision, and the court makes this association. Finally, the court proposes that the second part of the test should endeavor to determine what it is that the applicant has invented. To answer that question the claim as a whole must be analyzed along with the specification.[87]

At this point the court delves into the issue at hand. As each of the claims includes a limitation that calls for calculating the difference between two quantities, the first step clearly results in the determination that an algorithm is directly or indirectly recited in the claims.[88] The court then moves on to the second step. For the reader to understand the difference in reasoning two claims are reproduced here:

> 5. A method of displaying data in a field comprising the steps of:

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[86] *Abele*, 686.

[87] *Abele*, 687.

[88] *Abele*, 687.

> calculating the difference between the local value of the data at a data point in the field and the average value of the data in a region of the field which surrounds said point for each point in said field, and
>
> displaying the value of said difference as a signed gray scale at a point in a picture which corresponds to said data point.
>
> 6. The method of claim 5 wherein said data is X-ray attenuation data produced in a two dimensional field by a computed tomography scanner.[89]

The court concludes that claim five concerns itself only with the mathematical algorithm and thus is not statutory subject matter. Claim six, however, is held to be statutory, despite depending from claim five. The court reasons that the additional limitation that the method is applied to CAT scan attenuation data is sufficient to change the determination. Looking to the specification, the court finds that to produce x-ray attenuation data there are required additional physical steps:

> Were we to view the claim absent the algorithm, the production, detection and display steps would still be present and would result in a conventional CAT-scan process. Accordingly, production and detection cannot be considered mere antecedent steps to obtain values for solving the algorithm as in *In re Richman*, cited by the examiner. Indeed, claim 6 presents data gathering steps not dictated by the algorithm but by other limitations which require certain antecedent steps.[90]

Thus the court implements the "otherwise statutory" test that was proposed earlier by

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[89] *Abele*, 687.

[90] *Abele*, 687.

removing the algorithm and examining the remaining claim.

I. In re Iwahashi

The opinion of the CAFC in *Iwahashi* is much shorter than those we have previously examined but it nonetheless represents an important principle. The applicant's invention is an "autocorrelation unit," a circuit that performs certain autocorrelation operations on a sampled signal. The specification particularly points out the potential use of the device in pattern recognition, specifically voice recognition. The circuit operates by performing the autocorrelation using a formula that estimates "autocorrelation coefficients" instead of computing them directly, thereby saving time and simplifying the circuit.[91]

After a brief listing of the cases that had gone before, including those discussed above, the court goes on to use the *Freeman-Walter* test. The first test is clearly met as autocorrelation is a mathematical process implementing an algorithm. The court then finds that the second part is not met, and the claims are directed to statutory subject matter. The claim on appeal is a unit comprising: means for extracting..., means for calculating..., a read only memory..., means for feeding..., means for storing..., means for fetching and outputting..., and means responsive to.... The read only memory (ROM) is taken as a specific piece of apparatus and the other means for limitations are taken to "cover the corresponding structure, material, or acts described in the specification and equivalents thereof."[92]

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[91] *In re Iwahashi*, 12 USPQ 2d. 1908 (Fed. Cir., 1989), 1908-9.

[92] *Iwahashi*, 1912 quoting 35 USC 112 ¶6.

The PTO took the *Iwahashi* opinion to mean that the reference to the ROM was what made the claim suited to analysis as an apparatus instead of a method in this case.[93] Even with such a limited reading this could be instructive to the claims drafter; if a single specific piece of apparatus is recited, then the claim can be said to be drawn to statutory subject matter. However, as we shall see in our discussion of *Alappat* and *Donaldson*, below, the second portion of the court's reasoning concerning the interpretation of "means for" limitations is also important.

J. Arrhythmia v. Corazonix

This is the first case which we will discuss that has not come directly out of the patent office. Arrhythmia Research Technology, Inc. is the holder of a patent issued to Michael B. Simson. Dr. Simson had developed a technique that is used to monitor post heart-attack patients to determine if they have a high risk for ventricular tachycardia, a type of heart arrhythmia. In patients at risk for tachycardia a portion of the EKG signal contains a low amplitude, high frequency component. Dr. Simson's invention relates to signal processing of the EKG to detect and measure these components. After Arrhythmia Research brought suit against Corazonix for patent infringement, the patent was judged to be invalid on the basis of being drawn to nonstatutory subject matter. Arrhythmia Research appealed to the CAFC.[94]

The court applies the *Freeman-Walter-Abele* test for statutory subject matter, restating that test as follows:

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[93] Merges, 79.

[94] *Arrhythmia v. Corazonix*, 22 USPQ 2d. 1033 (Fed. Cir., 1992), 1034.

> It is first determined whether a mathematical algorithm is recited directly or indirectly in the claim. If so, it is next determined whether the claimed invention as a whole is no more than the algorithm itself; that is, whether the claim is directed to a mathematical algorithm that is not applied to or limited by physical elements or process steps. Such claims are nonstatutory. However, when the mathematical algorithm is applied in one or more steps of an otherwise statutory process claim, or one or more elements of an otherwise statutory apparatus claim, the requirements of section 101 are met.[95]

Once again, that an algorithm is present is fairly obvious as the claimed operations of converting and applying signals, as well as determining amplitude and comparing values, are clearly mathematical in nature. Proceeding to the second part of the test the court chooses the otherwise statutory aspect of the test, phrasing this as a determination of "what the claimed steps do."[96]

The court takes the preamble as a limitation insofar as it calls for the use of a EKG signal as the object of the manipulation of the subsequent steps. The signals are not pure numbers but rather "are related to the patient's heart function."[97] The invention makes use of a digital filter that is known to be useful for frequency filtering of digital waveforms. After digitization and filtering, the average magnitude of the signal is determined and

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[95] *Arrhythmia*, 1037.

[96] *Arrhythmia*, 1038.

[97] *Arrhythmia*, 1038.

compared against a predetermined level to test for high risk of tachycardia.[98]

The opinion states that "These claimed steps of 'converting', 'applying', 'determining', and 'comparing' are physical process steps that transform one physical, electrical signal into another. The view that 'there is nothing necessarily physical about "signals" ' is incorrect." The court further finds that the method is an "otherwise statutory process whose mathematical procedures are applied to physical process steps."[99]

Surprisingly, the court goes on to analyze separately the apparatus claims. One might expect that if a method were statutory then a device for performing that method would be as well. In the other cases we have examined the analysis for one was held to apply to the other. In this case, however, the court makes use of the *Iwahashi* decision to make its determination. Using that portion of *Iwahashi* that referred to the proper interpretation of §112 ¶6 the court looks to the specification for explanation of the means for language. It finds that "The Simson apparatus claims thus define 'a combination of interrelated means' for performing specified functions,"[100] as required under *Iwahashi*.

In addition, the court rejects the idea that if the output of a method or device is a number then it is unpatentable. This is found not to be determinative in itself. In this case the number has a physical meaning. It represents a specified heart activity and the court makes clear "That the product is numerical is not a criterion of whether the claim is

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[98] *Arrhythmia*, 1038.

[99] *Arrhythmia*, 1038.

[100] *Arrhythmia*, 1039.

directed to statutory subject matter."[101]

K. In re Donaldson

Donaldson is not a computer related case, nor does the invention in issue utilize a mathematical algorithm. It nonetheless bears on our discussion due to the impact on PTO interpretation of "means plus function" ("means for...") language. The invention is an air filtering device for collecting dust. A chamber contains a series of filters through which air passes. In such an air filter the dust collects on the surface of the filters, reducing efficiency. By periodically reversing air flow through the filters this accumulated dust is cleared, then the dust falls to the floor of the chamber and may be removed from the chamber. In prior art devices there is a tendency for dust to cake and thus not be properly removed from the chamber. In the present invention at least one wall of the chamber is flexible, and when air flow is reversed, the flexible wall bows outward due to the pressure, breaking up the caked dust and allowing it to be removed.[102]

The first claim, in which the flexible wall is recited as a "means responsive to pressure increases" was rejected as anticipated by a prior art filtering device. The board sustained this rejection, since the flexible limitation was not positively recited.

In a ruling similar to the portion of *Iwahashi* that was ignored by the PTO, the court holds that the board is not properly interpreting the means plus function language:

> The plain and unambiguous meaning of paragraph six [of 35 U.S.C. 112] is that one construing means-plus-function language in a claim must look to the

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[101] *Arrhythmia*, 1039.

[102] *In re Donaldson*, 29 USPQ 2d. 1845 (Fed. Cir., 1994), 1846-7.

> specification and interpret that language in light of the corresponding structure, material, or acts described therein, and equivalents thereof, to the extent that the specification provides such disclosure. Paragraph six does not state or even suggest that the PTO is exempt from this mandate....[103]

In the past the courts have looked at 35 U.S.C. 112, ¶6 in exactly this way when deciding infringement suits. The PTO, as we have seen, has not looked to the specification for purposes of determining patentablilty. The court in *Donaldson* simply states that this double standard is not in accord with the statute nor the legislative history of the patent act. The language of *Donaldson* is much more clear than *Iwahashi* in stating what the Federal Circuit expects from the PTO in the future.

The PTO responded to this decision with a new guideline for claim examination.[104] It directly adopts the language of the court stating, "... effective immediately, examiners shall interpret a §112, 6th paragraph 'means or step plus function' limitation in a claim as limited to the corresponding structure, materials or acts described in the specification and equivalents thereof...."[105] This change in means plus function interpretation affects examination of devices such as that presented in *Iwahashi*, as we shall see next in our discussion of *In re Alappat*.

L. In re Alappat

Alappat's invention concerns the production of a smoothed oscilloscope trace.

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[103] *Donaldson*, 1848.

[104] 1162 OG 59.

[105] 1162 OG 59.

When digital oscilloscopes are used to display analog waveforms, smooth vectors are represented by jagged images. Alappat makes use of an anti-aliasing system to smooth the image. By illuminating pixels along the path of the function at varying intensities, the image can be somewhat blurred, providing a smooth trace. The claim in issue is drawn to a rasterizer, the rasterizer converting vector data into "anti-aliased pixel illumination intensity data" for display. This rasterizer is claimed as comprising four elements, each in "means-plus-function" language. The first two elements determine distance between points, the third normalizes distance, and the fourth outputs illumination intensity data as calculated from the output of the third.[106]

The examiner rejected the claims as nonstatutory. On appeal, the board reversed the rejection using the type of analysis required by *Donaldson* with respect to means plus function claims. A second board expanded the first board's decision by essentially reversing it, holding that this analysis was incorrect, and that the PTO was not bound by §112, ¶ 6. That a second board was convened was somewhat abnormal and the discussion of that issue constitutes about half of the court's opinion. However this issue will not be treated here. The second board read the claims as a process drawn to "a mathematical operation, [forming] a 'mathematical algorithm for computing pixel information,'" and thus unpatentable.[107]

The court looks to the precedent of *Donaldson* to refute the second board's contention that the PTO is not bound by §112, ¶ 6. Therefore, the court reasons, the

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[106] *In re Alappat*, 31 USPQ 2d. 1545 (Fed. Cir., 1994), 1551-3.

[107] *Alappat*, 1554.

second board erred in interpreting the claims in such a broad manner. Additionally, the court rejects the second board's contention that the apparatus should be analyzed as a process. In previous cases, including for example *Abele*, claims made up entirely of means were analyzed as processes, the court reasons, only because they did not have the *Donaldson* mandate to look to the specification. The court here rewrites the claims, replacing "means for" language with the structure as disclosed in the specification. Using that analysis the court finds that the claims "unquestionably [recite] a machine, or apparatus, made up of a combination of known electronic circuitry elements."[108]

Despite having already shown that the claims are drawn to a machine, the court continues its analysis, stating that precedent may imply a mathematical algorithm exception even for a true machine claim. The court here drops back to the *Diehr* holding that there are three categories of unpatentable subject matter, "laws of nature, natural phenomena, and abstract ideas."[109] Looking additionally to *Flook* and *Benson*, the court states that "certain mathematical subject matter is not, standing alone, entitled to patent protection," but, that the Supreme Court "never intended to create an overly broad, fourth category of subject matter excluded from §101." It goes on to state that in each case, mathematical subject matter, standing alone, simply comprises abstract ideas, as prohibited under *Diehr*. Further, the court holds that "the proper inquiry in dealing with the so called mathematical subject matter exception to §101 alleged herein is to see whether the claimed subject matter as a whole... represents nothing more than a 'law of nature,' 'natural

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[108] *Alappat*, 1555.

[109] *Diehr*, 7.

phenomenon,' or 'abstract idea.'"[110] The court then characterizes the invention in issue as a combination of elements forming a machine that acts on sampled data to produce illumination intensity data, rather than simply circuit elements that perform mathematical operations. Given this characterization of the invention, the question of whether this is an abstract idea or law of nature must then be answered in the negative. In addition, the preamble to the claim recites a rasterizer and the court finds that this is not a mere field of use limitation as in *Walter*.

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[110] *Alappat*, 1557.

Chapter II: Case Study - Method and Apparatus for Non-Destructive Evaluation of Composite Materials With Cloth Surface Impressions

A. Background of the Invention

The case we will examine concerns an invention disclosure by Dr. Eric Madaras of the NASA Langley Research Center in Hampton, VA. Part of Langley's focus on aeronautical applications includes research into instrumentation and methods for materials characterization.

The application for patent, the patent examiner's office action, the reply to the office action and the issued patent are all included in Appendix A for the reader to examine.

Before delving into the nature of the invention itself we will examine the background. Historically, inorganic engineering materials are generally classified as ceramics, metals and polymers. Each type has particular strengths and weaknesses and depending on the engineering application an appropriate class of material may be chosen. In modern applications some combination of characteristics is often desirable, and as a result a "new" class of materials has appeared: composites. One example of a composite material would be graphite fibers embedded in a polymer matrix. This can obviously be extended to any combination of materials, and in fact it is somewhat misleading to consider composites to be a new development. For example, the common "brick" used for houses and other construction is a baked ceramic reinforced with straw (carbon fiber); this technology dates several centuries into the prechristian era. Another fairly common building material such as concrete with embedded steel reinforcing bars could be considered to be a composite material. In this case, however, we are considering artificially synthesized polymer matrix composites such as those used in the aircraft industry.

In the manufacture of this type of composite the curing process often takes place inside a vacuum bag. To aid in the removal of the bag after curing, a Teflon polymer coated release cloth is interposed between the bag and the workpiece. This cloth produces a surface impression on the cured piece, and it is this surface impression which is of interest here.

In the ultrasonic evaluation of materials one figure of interest is the integrated polar backscatter. Integrated polar backscatter is determined by insonification of a workpiece at an angle and detecting the amount of energy returned along the same angle. If the piece has a smooth surface and no interior defects, the value will be low. If interior discontinuities are present, some portion of the impinging waves will be returned and detected. The returned energy may be interpreted as delaminations, inclusions, cracks and other defects.

In the case where a cured piece retains surface impressions (surface defects) from release cloth the integrated polar backscatter will be nonzero, even in a piece with zero internal defects. It would be useful to be able to correct for this effect, and it is this correction that is achieved through the invention that is discussed here.

B. The Invention

As discussed above, release cloth impressions adversely affect measurement of integrated polar backscatter by increasing the backscattered energy. One method of reducing the effect of surface texture is by covering the surface of the piece with a coating that matches the acoustic impedance of the composite. The coating will essentially provide a smooth surface for testing. The drawback is that providing and then removing the coating is time consuming and costly.

The effects of a regular series of surface impressions may be modeled as a diffraction grating.[111] In such a model it becomes apparent that the noise contains a strong frequency dependance, and this conclusion is borne out by experiment. Figure 6 in the application demonstrates the tall, narrow spikes that may be observed when the power spectrum is examined in the frequency domain.

To eliminate this frequency dependent information from integrated polar backscatter measurements the following system may be employed. After collecting the backscatter data, one eliminates that data which is gathered from the frequency ranges that represent information collected from the surface impressions. The application for patent includes all of the appropriate background and 10 claims directed to methods and apparatuses for achieving the removal of particular frequencies from a frequency power spectrum.

C. The Application

The initial application was prepared for LaRC by outside counsel. The full text is

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[111] Madaras, et. al., *Measured Effects of Surface Cloth Impressions*, 2.

available in Appendix A, however we will summarize the claims as presented. The first claim is drawn to a method comprising: (a) insonifying scan sites, (b) calculating a power spectrum for each site, (c) adding several spectra, (d) identifying frequency ranges of peaks, (e) eliminating ranges containing peaks, and (f) integrating the remaining power spectrum. The second claim further defines the identification process of step (d). This includes: smoothing the power spectrum, plotting the first derivative of the power spectrum, finding zeros of the first derivative, finding peaks or valleys adjacent to zeros, determining amplitude of those peaks, plotting lines on either side of the peaks, the lines having slopes equal to the amplitude, and defining a peak area as the frequency range between each pair of adjacent intersecting lines. The third claim is similar to the second but employs a different algorithm for locating peaks wherein the amplitude of each peak is divided by the difference between the maximum and minimum values of amplitude and then applying a threshold test to that value. Claim four is directed to an apparatus for performing the method. It comprises: (a) a transducer, (b) amplifying means, (c) means for converting time domain signals to frequency power spectra, (d) peak detecting means, (e) frequency range detecting means, (f) means for summing frequencies excluding identified ranges, (g) means for integrating power spectra over the same frequencies, (h) means for calculating a quotient of the values found in (g) and (f) [this value is integrated polar backscatter], and (i) means for comparing integrated polar backscatter with a reference value. Claims five, six and seven further define particular means as recited in claim four. Claims six and seven recite means (c) through (i) as being a programmed digital computer. Claim eight is drawn to a method of correctly computing integrated polar backscatter with similar limitations to those recited in claim one. One addition is a step specifically reciting the recording of a power spectrum as opposed to calculating a power spectrum. Claims nine and ten are related to claim eight in the same manner that claims two and three are related to claim one.

D. Examination and First Office Action

In the first official action of the U.S. Patent and Trademark Office, all ten claims are rejected and other objections are raised by the examiner.

In the specification, reference is made to a paper presented at the 19th Annual Review of Progress in Quantitative Nondestructive Evaluation, and the paper is incorporated by reference. The examiner objects to this attempted incorporation by reference pointing out that the Manual of Patent Examining Procedure (MPEP) provides that essential material may be incorporated by reference only if that reference is a US patent or an allowed US application for patent.[112]

The action then proceeds to a rejection of the claims. The first issue addressed is a rejection under 35 U.S.C. §101, and all ten claims are rejected as being directed to nonstatutory subject matter.

First the examiner states that the *Freeman-Walter-Abele* test will be relied upon in coming to the conclusion that the invention is nonstatutory. Second, the issue of means plus function language is raised.

Due to the means plus function format of the apparatus claims, the examiner states that they are treated as method claims for the purpose of the statutory analysis under

[112] MPEP 608.01(p)

§101, citing *Walter* and *Abele*. The examiner states further that in cases in which a computer is involved in performing calculations, "...the burden must be placed on the applicant to demonstrate that the claims are truly drawn to specific apparatus distinct from other apparatus capable of performing the identical functions."[113] Failing to meet this burden results in the apparatus claim being examined as if it were a method claim.

The examiner returns to the *Freeman-Walter-Abele* test and begins by making a statement of the test and quoting heavily from *Abele*. Using the first step of the test the examiner determines that a mathematical algorithm is recited indirectly by the claims, such language as calculating a power spectrum and identifying peaks being held to indicate mathematical operations.

In employing the second step the examiner relies on the otherwise statutory analysis as proposed by the court in *Abele*. After removing the mathematical steps the examiner characterizes what remains of the claims as consisting of a field of use limitation, data gathering and post-solution activity.

Citing *Diehr* the examiner states that a field of use limitation is insufficient to render a claim statutory. Each preamble is then recited and stated to set forth a field of use for the algorithm that follows.

As for the data gathering steps the examiner declares that, "Claimed steps which 'merely determine values for the variables used in the mathematical formulae used in making the calculation' may be insufficient to change a nonstatutory method of calculation

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[113] Examiner's action, p. 3.

into a statutory process."[114] This argument is backed by quotes from several cases from the CCPA and the Federal Circuit which declare that to make use of any algorithm, data must first be obtained and that the methods of obtaining data are known and old in the art.

Citing *Walter* the examiner argues that if the end product of a method is a pure number then the invention is nonstatutory. As for the post-solution activity, the examiner draws a parallel between the present invention's comparison with a reference value to the adjusting of an alarm limit in *Flook* and states that this type of post-solution activity is insufficient to render a claim statutory.

The examiner then draws his argument to a conclusion:

> The signal is not claimed to be applied to a physical device to control the device nor is the signal used to 'refine or limit' process steps from some overall claimed process.... It is readily apparent that when Claims 1 to 10 are each taken as a whole, they are directed to the preemption of a mathematical algorithm, and thus are non-statutory.[115]

The remainder of the office action is concerned with rejections under 35 U.S.C. §112 for various small problems with the claim language. A single piece of prior art is cited but is not used as the basis for a rejection under §§ 102 or 103.

E. Response to the Office Action

The response to the office action was prepared by the author with Linda Blackburn,

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[114] Examiner's action, p. 8-9.

[115] Examiner's action, p 11.

a patent attorney at Langley Research Center.

A response to an office action is usually composed of two main sections. The first part is an amendment, in which words may be added to or deleted from the application as filed. Often some claims are deleted and new claims are added. The second portion, which is designated "Remarks," explains the additions and deletions of the amendment and contains the patent practitioner's arguments to rebut the examiner.

In the present response, some clarifications are made in the specification. The word "regular" is inserted in several places to clarify that the method is useful with objects that have a regular surface texture. This is because the theory depends on a diffraction grating model for ultrasound reflection. The improper incorporation by reference of a document other than a US patent is removed, and two paragraphs are added to disclose the theoretical analysis that leads to the method.

Key changes are presented in the section dealing with the claims. Claims 8-10 are deleted outright. No argument is presented by the response concerning these claims. While it is possible that these claims could be drawn to statutory subject matter, it would seem to be a difficult argument to make. Each of these claims, according to their preambles, is drawn to a method to correctly compute integrated polar backscatter. A method of computing a value is fairly clearly outside of the regime of things patentable. It could be argued that these methods of computing include such physical steps as insonifying a workpiece and receiving a return signal. However, little protection for the invention is lost by abandoning these claims, while the argument for patentability for the others becomes more easy to make.

The independent claims, one and four, are also deleted. They are recast as claims 11 and 12 respectively. The amount of rewriting which would be necessary to make these claims more clearly patentable makes it desirable for both the examiner and practitioners if these claims are completely redone.

Claim 11 is altered from claim one in several ways. A detection stage is added after the insonification step. The return signal is said to be transformed into a power spectrum instead of having a step directed to the calculation of a power spectrum. Finally, after the corrected integrated polar backscatter is determined, a display step is added.

The series of steps: production, detection, display should be familiar to the reader. We recall from *Abele*'s otherwise statutory analysis these are the steps claimed in the CAT scan invention when the algorithm is removed. The amendment's purpose here is to put the current claims into a format that is parallel to claims that were found to be patentable in a previous case.

In the apparatus claim, 12, the differences from original claim 4 are not so great. The several means (d), (e), (f), (g), (h), and (i) are combined into one processing means (d) that is capable of performing all six functions. This brings the claim into line with the specification. In the specification, all of these functions are performed by a programmed digital computer. Since there is no basis for claiming six different devices, the claim should be properly drawn to a single device. This change is not in response to a comment by the examiner but rather to put the practitioners in position to assert that the new rules concerning the interpretation of means for language should be used by the examiner.[116] As was discussed before, these rules require that the examiner look to the specification to interpret means for clauses. Therefore it is important to be sure that means for clauses have a proper basis in the specification.

The other claims are amended to make them clearer and to remedy the §112 rejection.

The first portion of the remarks section of the reply is used to summarize the status of the case (i.e. to state which claims are rejected and how they have been modified). Then after a justification for the changes in the specification the arguments with respect to §101 begin.

First, the argument that the examiner must look to the specification for interpretation of the means plus function clauses is made. Citing the Official Gazette announcement it is argued that the examiner must limit this interpretation to structure described in the specification and equivalents thereof.[117] This line of reasoning is also used to argue that the apparatus claims should not be treated as process claims.

Next, the result of the inquiry under the *Freeman* test is questioned. The conclusion under the first portion is not argued, nor is it conceded, however. The determination based on the second part of the test, though, is traversed. In reply to the examiner's request to point out underlying process or physical elements the applicant

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[116] The *Donaldson* decision was not available to the examiner until after the office action was complete.

[117] 1162 OG 59.

responds:

> ...the underlying process in the present invention includes: 1) insonifying a composite specimen to produce backscattered ultrasound that varies according to physical characteristics of the specimen, 2) detection of the backscattered ultrasound, 3) transformation of the detected ultrasound to an electronic signal, 4) display of the electronic signal, and 5) comparison of the electronic signal from the test specimen to electronic signals obtained from similar composite samples containing known defects in order to identify the defects in the test specimen.[118]

The parallel to *Abele* in the steps of production, detection and display is then pointed out. Several other cases that are concerned with inventions containing a similar set of steps are cited.

Then the argument is made that the claims are directed to a physical process and to a device for performing that physical process. The removal of artifacts from signals created in the performance of this physical process is an additional step added to the underlying process. This analysis proceeds by stating that the underlying process and device are statutory and that the addition of the algorithm does not render them nonstatutory. This language is borrowed heavily from the court's opinion in *Abele* to leave as little room as possible for argument by the examiner. It should be noted that it is rare for case law to be utilized in arguing with the examiner.. Most examinations proceed

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[118] Response to Office Action, 11.

with reference only to the rules put forth in the MPEP. In this prosecution, however, the examiner first made reference to case law, so it was clearly appropriate to rebut the examiner's assertions by applying case law.

Each of the examiner's individual arguments concerning field of use limitations, end products, data gathering and post solution activity are then addressed.

The examiner's statement that the algorithm is merely presented and solved and that the preamble merely presents a field of use is contested. It is argued that the algorithm is applied to transform a signal which represents information about physical characteristics of a sample. Referring to a decision by the Board of Patent Appeals and Interferences, it is stated that the preamble limits the claims to a specific use (i.e. processing ultrasonic signals from composite materials) thus leaving all other uses of the algorithm in the public domain.[119]

That the end product is a pure number is also disputed. The end product is asserted to be not merely a number but rather representative of real physical characteristics of a material being inspected. This type of numerical output is in line with the corrected, noiseless signal of *Johnson*, or the isolated high frequency signal found in the invention in *Arrhythmia.*

The contention that steps outside of the algorithm are merely data gathering and insignificant post solution activity are not separately addressed. Rather, the above argument that the underlying process is statutory is relied on.

The remainder of the remarks is concerned with remedying some minor problems

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[119] *Ex Parte Veldhuis,* 1992 Pat. App. LEXIS 39.

with indefinite language.

E. Final Action

The next action by the PTO was to issue a notice of allowance and to request formal drawings and payment of the issue fee.

Chapter III: Conclusions

The Supreme Court in *Benson* specifically states that that decision does not preclude a patent on any computer program.[120] It is this statement which holds open the door for the rest of the cases that follow. Had the court simply banned all software patents, the analysis of these later cases would have been simpler. However, many related questions would not be as well explored. The lines between software and device inventions are growing more and more blurred. Almost any circuit that can be designed can be simulated with software and much software can be hardwired into circuit form. A straightforward ban on software patents would not eliminate the controversy. The inventions explored in this work depend on mathematics to one degree or another but the author would not agree that they are properly characterized as software.

The test put forth under *Abele* would seem to be the most reasonable standard offered to date. Is the process in question otherwise statutory when viewed in the absence of a mathematical algorithm? If so, it is logical that the addition of an algorithm should not remove the process from its statutory classification.

Strangely, however the court seems to have abandoned this standard. *Alappat* does more than back up *Donaldson* as to the interpretation of "means-plus-function" language. It also takes on the statutory subject matter inquiry in a manner that completely ignores

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[120] See note 13.

the precedent of the CCPA and the Federal Circuit in *Freeman*, *Walter*, *Abele* and others, and instead returns to the Supreme Court's opinions in *Benson*, *Flook*, and *Diehr*. The court returns to the *Diehr* analysis, determining whether the subject matter as a whole is directed to a law of nature, natural phenomenon, or abstract idea. It is not clear why this complete change of direction occurs but it seems to be real as the court follows the same course in deciding *Warmerdam*[121] and *Lowry*[122] later in 1994. While the CCPA and Federal Circuit cases do not overrule the Supreme Court opinions they do provide useful principles for understanding those cases. Unfortunately, *Alappat* seems to abandon those principles.

Despite retreating to *Diehr*, the court does not go back to the physical process analysis that the Supreme Court used in that case. The invention in *Alappat* is drawn to a device for smoothing display information. This function is not unlike the interpolation of picture elements that was the subject of the invention rejected as nonstatutory in *Walter*. Unfortunately the *Diehr* analysis remains as unclear and open to argument after *Alappat* as it was when it first put forth.

The argument can be made that the statutory subject matter inquiry has been the wrong one to make all along. It has been well established that inventions making use of mathematical algorithms are statutory subject matter. If either the *Freeman-Walter-Abele* test or the *Diehr* inquiry is used there will be some class of patentable inventions that includes signal processing, systems control, and other computer implemented devices.

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[121] *In re Warmerdam*, 31 USPQ 2d. 1754 (Fed. Cir., 1994).

[122] *In re Lowry*, 30 USPQ 2d. 1031 (Fed. Cir., 1994).

What seems to be forgotten in all of these cases are the other two doors to patentability. The court is often worried that by patenting the application of a known algorithm to a known process, an inventor will effectively preempt the use of that algorithm when it properly belongs in the public domain. In many of these cases, under a point of novelty analysis, the result has been an examiner's rejection under §101. The courts tend to overturn this type of rejection under the *Bergy* doctrine that point of novelty inquiries confuse the statutory subject matter question with that of novelty or obviousness. An invention that merely applies known algorithms to known processes may well be obvious and thus be properly rejected under §103 despite passing the §101 inquiry.

The case study serves as a good example of how the obviousness analysis can work. Once it is known that the noise caused by regular surface impressions is concentrated into high amplitude spikes in narrow frequency ranges it is obvious that the removal of these ranges will reduce the effects of the surface impressions. The question then becomes not whether the invention is statutory subject matter but rather whether one skilled in the art would find it obvious. While it could be argued that this is simply a case of shifting the analysis there is one certain benefit to such a shift. The obviousness determination is a problem that is much better understood by examiners, practitioners and the courts alike, thus the type of confusion so rampant now should be reduced. In the case study, the nature of the noise was not known prior to the invention by the applicant of his method so a patent should be granted. A patent here does not inhibit others from removing certain frequency ranges from signals, nor does it allow the grantee to remove a useful process from the public domain. It simply allows the inventor to capitalize on the research and development that went into producing something new and useful, exactly as the patent system should.

Despite over twenty years of litigation and evolution of the patentability issue it is still not clear what is happening in the courts. Moreover, in some ways, what is decided by United States courts is becoming less and less important. The US position in the world's economy has diminished considerably as Asian economies grow and Europe works towards unification. On the other hand, the US is still a world leader in high tech development and in the field of patent law. Therefore any standard adopted by US courts will likely be an important influence throughout the world in the years to come. It is crucial then that such a standard fully separates the questions of subject matter, novelty and obviousness.

APPENDIX: CASE STUDY PROSECUTION MATERIALS

METHOD AND APPARATUS FOR NON-DESTRUCTIVE EVALUATION OF COMPOSITE MATERIALS WITH CLOTH SURFACE IMPRESSIONS

Origin of the Invention

The invention described herein was made by an employee of the U.S. Government and may be manufactured and used by or for the government for governmental purposes without the payment of any royalties thereon or therefor.

Background of the Invention

Field of the Invention

The present invention relates generally to non-destructive evaluation of materials by ultrasonic methods, and specifically to the quantitative evaluation of the internal condition of composites by the measurement of Integrated Polar Backscatter from a composite material insonified by an ultrasonic transducer at a non-normal angle of incidence.

Description of the Related Art

In a known method for quantitative evaluation of the internal condition of a composite material, the composite is insonified by a single ultrasonic transducer at a non-normal angle of incidence, and a quantity called the Integrated Polar Backscatter is used as a measure of the condition of the composite. The Integrated Polar Backscatter is defined as the total energy of the backscatter signal detected by the transducer over preset frequency ranges, divided by the sum of the frequencies in the preset frequency ranges. The backscatter signals are usually normalized by comparison with the backscatter signal obtained from a reference object, such as a polished stainless steel plate in the same test setup.

When the composite material being tested has a smooth surface, the non-normal angle of incidence of the ultrasonic signal causes the reflected portion of the incident signal to be directed away from the transducer, so it does not contribute to the detected signal. The rest of the incident signal is refracted into the composite, where matrix cracking, porosity, inclusions, or other defects will cause a backscatter signal to be returned to the transducer. Integrated Polar Backscatter accordingly provides an accurate measure of the condition of a composite that has a smooth surface.

In practice, the surface of a composite material is not totally smooth, but has a surface texture caused by impressions from a "release cloth", which is a fine mesh cloth impregnated with teflon, used to keep the composite from sticking to the surfaces of the curing press. Such a surface texture causes some of the reflected ultrasonic signal to be directed back to the ultrasonic transducer, so the Integrated Polar Backscatter will have a constant component, independent of the condition of the interior of the composite. This surface backscatter obscures variations in the Integrated Polar Backscatter caused by internal defects, and can make the Integrated Polar Backscatter useless as a quality measure, unless precautions are taken to alleviate the effect of the surface texture.

The obvious remedy for a surface texture is to remove it. Grinding is not a useful method, but a strippable coating of a material with ultrasonic properties matching those of the composite can be applied to the surface of the composite to smooth out the surface texture and effectively eliminate the detrimental effect of the cloth impressions. The application of a coating before the ultrasonic evaluation, and stripping it off afterwards, are time consuming and expensive processes, however. Sometimes quality approval of both the coating material and the application and stripping processes would also be required, which effectively could rule this method out.

An alternate method for reducing the backscattering effect of the cloth impressions involves careful azimuthal alignment of the transducer and the composite material until minimal surface backscatter is obtained. A minimum in the surface backscatter is obtained when the incident signal is parallel to the impressions from either the weft threads or the warp threads in the release cloth. Generally, the surface backscatter has an absolute minimum when the incident signal is in-between the weft threads and warp threads directions. This alignment method can reduce the effect of surface backscatter to tolerable levels in most cases, but the azimuthal alignment is a cumbersome process that is difficult to automate.

Summary of the Invention

It is an object of the present invention to provide a new method and apparatus for accurate ultrasonic evaluation of the internal condition of a composite material having surface impressions from a release cloth through the measurement of Integrated Polar Backscatter.

Another object of the present invention is to provide a method for correctly computing the quantity known as Integrated Polar Backscatter when applied to composite materials with cloth surface impressions.

It is still another object of the present invention to provide a method and apparatus for evaluating the interior of a composite material through the measurement of Integrated Polar Backscatter that can identify and remove signal components caused by surface texture on the composite material.

Even another object of the present invention is to provide a method and apparatus for ultrasonic evaluation of the interior of a composite material by polar backscatter, including elimination of data collected over particular frequency ranges associated with surface texture.

It is a still further object of the present invention to provide a new method for evaluation of the interior condition of a composite material by measurement of the quantity known as Integrated Polar Backscatter, which involves automatic detection of effects from surface texture and automatic elimination of such effects from the measured quantity.

In order to achieve the foregoing and other objects, in accordance with the purposes of the present invention as described herein, a method for non-destructive evaluation of composite materials with cloth surface impressions comprises the steps of insonifying a series of scan sites on the composite material sequentially with ultrasound at a fixed polar angle larger than zero, recording a power spectrum of the polar backscatter for each scan site, adding the measured backscatter power spectra from several of said scan sites to form a composite power spectrum for polar backscatter, identifying frequency ranges in the composite power spectrum where peaks occur, eliminating the identified frequency ranges from each power spectrum for scan sites of the composite material, and integrating the remaining power spectrum for each scan site to obtain a value for Integrated Polar Backscatter for each scan site substantially free from errors caused by cloth impressions on the surface of the composite.

Brief Description of the Drawings

The accompanying drawings illustrate several aspects of the present invention and, together with the descriptions, serve to explain the principles of the invention.

Figs. 1(a) and 1(b) are an enlarged top view and enlarged sectional view, respectively, showing the surface of a composite material with release cloth imprint;

Fig. 2 is a partly schematic illustration of an apparatus for performing the present invention;

Figs. 3(a), 3(b) and 3(c) are graphs illustrating frequency spectra for reflected energy at various polar angles Θ;

Figs. 4(a), 4(b) and 4(c) are schematic views illustrating different origins of backscatter signals returned from a composite material;

Fig. 5 is a flow chart for a method of computing Integrated Polar Backscatter with surface effects eliminated; and

Figs. 6(a), 6(b), 6(c) and 6(d) are graphs illustrating different steps in the method for eliminating frequency ranges containing the surface backscatter signal.

Detailed Description of the Preferred Embodiments

Fig. 1(a) is an enlarged top view of a composite material, such as a sheet of epoxy/graphite laminate, with a typical surface texture. Fig. 1(b) is an enlarged sectional view taken along line 1b-1b in Fig. 1(a) through the surface of the same material. The depressions visible in Fig. 1(b) are caused by a release cloth used during manufacture to prevent the laminate from sticking to the surfaces of a curing press. The release cloth is stripped off the laminate after the curing is completed.

Fig. 2 is a partly schematic illustration of an apparatus for ultrasonic evaluation of a composite material 110 by measurement of Integrated Polar Backscatter according to the present invention. An ultrasonic transducer 120 is aimed at a composite material 110 at a predetermined polar angle Θ and a predetermined azimuthal angle ϕ. The transducer 120 is typically a broadband transducer with 5 MHz center frequency, 4 inch focal distance, and 0.5 inch transducer width, and it is used in a pulse echo mode. Both the transducer 120 and the composite material 110 are immersed in water or some other suitable coupling medium during measurements.

In order to scan a selected area of the composite sample material 110, the transducer 120 is arranged movable relative to the composite sample material 110 while the polar angle Θ and the azimuthal angle ϕ are kept constant. After a measurement has been made at one scan site, the relative position is changed by a small increment, e.g. 1/16 inch, and a new measurement is made at the new scan site. This process is repeated until all desired scan sites have been measured. The area insonified by the transducer 120 is typically about 1/4 inch wide, which is larger than the distance between successive scan sites, so successive scans overlap.

A pulser/receiver system 130 contains a spike generator 140, which periodically generates a spike of approximately -150V to approximately -300V, causing the transducer 120 to emit an ultrasonic wave front aimed at the composite material 110. The pulser/receiver system 130 also contains an amplifier 150 for amplifying backscattered RF signals received by the transducer 120, and a 5 μs stepless gate (not shown), which is set to open just before the first reflection is received by the transducer 120. A suitable amplifier 150 is Metrotek MR 106 with a Metrotek MG 701 stepless gate. The output of the amplifier 150 is fed to a spectrum analyzer 160, e.g. a Hewlett Packard 8557 Analog Spectrum Analyzer, which converts the detected time domain signal into a power spectrum and displays it. The signal from the amplifier 150 can alternatively be fed to a device for performing a Fourier transform of the time domain signal, for instance a digital oscilloscope capable of displaying a Fourier transformed frequency plot. In either case, in Figs. 3(a) through 3(c), a power spectrum of the backscatter signal is displayed with frequency along the abscissa, and the square of the signal strength along the ordinate. The energy in any frequency band is then the area under the graph line in the frequency band.

The reflected signal is typically expressed as a ratio of the amplitude output of the amplifier 150 for the measured backscatter from a composite material as compared with the amplitude of the signal output of the amplifier 150 from a standard material in place of the composite material 110, e.g. a polished metal plate. This normalized signal amplitude is used in all calculations. The normalized amplitude spectrum and power spectrum are commonly displayed on a logarithmic scale and expressed in decibels (dB), but the calculations described below are ordinarily based on linear data values.

The output from the spectrum analyzer or digital oscilloscope 160 is fed to a computer 170, which contains circuitry for controlling the gathering of data, and programs for eliminating signals generated by surface texture on the composite material 110, as will be described in detail below.

Figs. 4(a) through 4(c) illustrate three types of backscattered signals, which are detected by the transducer 120 and forwarded to the spectrum analyzer 160. Lines 115 are lines normal to the surface of the composite sample material 110.

Fig. 4(a) shows backscatter from the surface of the composite sample material 110. This surface backscatter is negligibly small when the composite sample material 110 has a perfectly smooth top surface, because the signal reflected by the surface in that case will exit to the right of the normal 115 when the polar angle Θ is larger than zero. If, however, the surface of the composite sample material 110 has a surface texture, e.g. impressions from a release cloth as shown in Figs. 1(a) and 1(b), the surface texture can cause a significant amount of surface backscatter. This surface backscatter can become so large that it dominates the total backscatter signal. It is the object of the present invention to eliminate its effect on the backscatter measurement.

Fig. 4(b) shows backscatter signal from the interior of the composite sample material 110 by an incident signal refracted into the sample material 110. A flawless composite material will produce a small amount of backscatter of this mode, caused by different sound velocities in the matrix material and the reinforcing fibers of the composite sample material 110. A composite material suffering from delaminations or other defects in the interior of the sample 110 will, however, produce a much larger backscatter signal, and it is this mode of backscatter signal that is desirable for evaluation of the quality of the composite sample material 110.

Fig. 4(c) shows backscatter signal from the far side of the composite sample material 110. This mode of backscatter causes only a small, substantially constant backscatter signal, which does not seriously affect the desired backscatter signal from the mode illustrated in Fig. 4(b).

The test apparatus shown in Fig. 2 has a transducer 120 that emits an ultrasonic beam with a transducer width of 1/4-inch, so a large number of the small depressions on the surface of the composite material 110 are insonified simultaneously, and the distance between adjacent peaks in the surface texture is comparable to the wavelength of the ultrasonic wave in the coupling medium (water), which is about 0.03 mm at the center frequency of the transducer 120. Under these circumstances, the surface texture on the composite material 110 acts as an ultrasonic grate, so ultrasonic waves will be deflected at different angles to the normal 115 depending on their frequencies. This means that the surface backscatter signal returned to the transducer 120 will contain one or more narrow frequency bands generated by this grating effect.

An experimental and theoretical analysis of the effect of surface texture is described in a paper with the title "MEASURED EFFECTS OF SURFACE CLOTH IMPRESSIONS ON POLAR BACKSCATTER AND COMPARISON WITH A REFLECTION GRATING MODEL", presented by the inventor, Eric I. Madaras, at the 19th Annual Review of Progress in Quantitative Nondestructive Evaluation, La Jolla, California, July 20-24, 1992. This paper is included and incorporated herein by reference, and is attached as Appendix A to the subject application.

Figs. 3(a) through 3(c) are graphs showing the power spectra obtained with the apparatus shown in Fig. 2, using samples of laminate with surface texture as illustrated in Fig. 1(b), for different polar angles Θ. The dots represent measured data, while the full solid lines represent data obtained from the theoretical analysis described in the paper referenced above. The agreement between theory and measurement is good. The way the frequencies where peaks appear in Figs. 3(a) through 3(c) change with the polar angle Θ is in itself clear indication that the peaks are caused by the grating effect of the surface texture on the composite sample material 110.

The total energy in a frequency range is defined as the area under a power spectrum between the ends of the frequency range. It is evident from Figs. 3(a) through 3(c) that the areas under the peaks are the major part of the total area under the power spectrum. These parts of the total energy are, however, caused by the surface texture of the composite material, as explained above, so they are independent of the interior quality of the composite material. Accordingly, a much improved measure of the interior quality of a composite material will be obtained if those frequency ranges where peaks occur in the power spectrum are excluded from the calculation of Integrated Polar Backscatter.

The frequency ranges to be excluded according to the present invention are those that exhibit significant peaks caused by the grating effect of the surface texture. These excluded frequency ranges can easily be determined for a particular composite material at a particular polar angle Θ and azimuthal angle ϕ, either manually or by a computer algorithm, as will be described below. Correct values for Integrated Polar Backscatter, independent of artifacts caused by surface texture, can then be obtained for later scan sites on the composite material 110 by integrating the power only over the frequency ranges not excluded.

Fig. 5 is a flow chart of a method for computer processing of the data received from the transducer 120 via the spectrum analyzer 160.

In step S110, the azimuthal angle ϕ of the composite sample material 110 is visually oriented relative to the transducer 120. The composite sample material 110 should in step S110 preferably be aligned so azimuth $\phi = 0$ corresponds to the direction of impressions from weft threads in the surface of the composite material 110, but exact alignment of the sample material is not necessary, as long as the azimuthal angle ϕ remains constant during the entire test sequence.

In step S120, the surface of the composite sample material 110 is scanned by the transducer 120 over an area of interest to obtain raw data.

In step S130, the raw time domain data from step S120 is next transformed into the frequency domain using a spectrum analyzer or digital Fourier transform methods, and the power spectrum is calculated. This power spectrum is normalized (calibrated) by a reference signal earlier obtained from a polished stainless steel plate used as a target instead of the composite sample material 110 to represent the power that is transmitted into the composite sample material 110. The recording of the raw time domain data and conversion to a power spectrum in the frequency domain can be made by modern digital oscilloscopes, which have internal numerical signal processing computers that are optimized for fast and efficient Fourier transforms and can internally store and subtract signals. A spectrum analyzer could instead be used to give the power spectrum directly. A spectrum analyzer often has very high fidelity, but may be slower. Alternatively, the conversion by digital Fourier transform methods could also be performed within the computer 170.

In step S140, it is determined if the frequency ranges affected by surface backscatter have been set. If they have not been set, which is the case when a new sample 110 is being analyzed, step S140 continues to step S150. If the frequency ranges have been set, step S140 continues to step S190.

In step S150, all of the data, or data from a few selected scan sites, are next averaged to form a composite power spectrum, which will be used to determine which frequency ranges are affected by surface backscatter. Scans over a small region can often be used to identify the frequency ranges of interest for the whole data set.

The processing after step S150 continues in step S160, where significant peaks are identified by using a maximum/minimum identification algorithm. The significant peaks can be selected by first identifying the maximum and minimum power amplitudes in the entire frequency range, and calculating the maximum minus minimum value. Significant individual peaks would then typically be defined as peaks with a peak maximum minus peak minimum value that is greater than 20% of the overall maximum minus minimum value, or in mathematical terms:

(peak max-peak min)/(max-min) > 0.2.

Maximum/minimum identification algorithms could scan the data set in a straight forward manner testing for peaks and minima, or alternatively, by numerically differentiating the power spectrum (in the linear domain) with respect to the frequency, and testing those results for positive to negative transitions, which will identify frequencies where the power spectrum has undergone a maximum. It may be necessary to smooth the data, e.g. by means of a low pass filter, in order to remove signal noise before the differentiation.

Fig. 6(a) is a plot of smoothed data from a composite sample material 110 of normalized power plotted with respect to frequency. The surface texture on the composite sample material 110 introduces the signal artifacts appearing as peaks in Fig. 6(a). It is easily calculated that a minimum power of 0.00298 occurs at a frequency of 3.1 MHz, and a maximum power of 0.10584 occurs at a major peak at a frequency of 5.4 MHz. The max-min is therefore 0.10286. At a 20% cutoff, there is only one other significant peak, located at a frequency of 10.3 MHz.

Fig. 6(b) is a plot of the first derivative of the data of Fig. 6(a). The two significant peaks can be identified by their positive to negative transitions points at frequencies 5.4 MHz and 10.3 MHz in the first derivative data.

In step 170 of Fig. 5, the widths of the major peaks are determined. This is easiest to do by testing for maxima and minima in the first derivative with respect to frequency. Such maxima and minima in the first derivative represent the frequency locations of the "half widths" of the peaks. From Fig. 6(b), the locations of the maximum and minimum positions identify the steepest slopes as well as the frequencies where they occur. In the case shown in Fig. 6(b), the locations are first peak left half width at a frequency of 4.8 MHz, first peak right half width at a frequency of 5.65 MHz, second peak left half width at a frequency of 9.6 MHz and second peak right half width at a frequency of 10.75 MHz.

In step S180 of Fig. 5, the frequency ranges to be used in the calculation of Integrated Polar Backscatter for each scan site are determined. Once the half width locations are found as explained above with reference to step S170, the values for the maxima and minima in the first derivative data give the slopes of the peaks at the half width locations. The straight lines shown in Fig. 6(c) are calculated by step S180. They are tangents to the slopes of the peaks at the frequencies calculated under step S170, and their slopes are defined by the values of the maxima and minima in the first derivative with respect to frequency at those frequencies, as illustrated in Fig. 6(b). The resulting intercepts with the abscissa are frequencies of 4.6 MHz, 6.05 MHz and 9.05 MHz. Each frequency range between a pair of intersections spanning a peak represents a frequency range tainted by surface backscatter from surface texture, and all such frequency ranges should be eliminated from the calculation of the Integrated Polar Backscatter. Only the remaining frequency ranges are identified in step S180 of Fig. 5, and only these frequency ranges will be used in calculating the Integrated Polar Backscatter for each scan site.

Fig. 6(d) is a graph showing a normalized power spectrum for the resulting usable frequency ranges for analyzing the composite sample material 110. The other frequency ranges have been excluded because these were determined by the above procedure as containing erroneous data due to surface texture. Thus, by integration over only the ranges indicated in Fig. 6(d), the effect of surface texture is eliminated from the calculated Integrated Polar Backscatter.

After the frequency ranges have been set by steps S150 through S180, step S140 proceeds to the procedure for integration and detection of flaws in steps S190 through S220.

In step S190 of Fig. 5, the usable frequency ranges defined in step S180 are summed, thereby defining the denominator in later calculations of Integrated Polar Backscatter.

In step S200 of Fig. 5, the power spectrum for each scan element previously recorded under step S130, or recorded separately later on, is integrated over the usable frequency ranges determined in Step S180 to obtain the total energy.

In step S210 of Fig. 5, the total energy for each scan site calculated in step S200 is divided by the summed frequencies calculated in step S190, to produce an Integrated Polar Backscatter value for each scan site by normalization.

Finally, in step S220 of Fig. 5, a visual map is generated, with each scanned site being identified by a small square or rectangle ("pixel"). The color or gray level of the pixel can be used to provide an image representing the amplitude of the integrated polar backscatter. This visual map can also be thresholded to produce a binary image representing good versus flawed material.

The present invention offers several important advantages over the prior art. A major advantage is that it requires no sample preparation for implementation. The present invention further requires only that digital data be obtained for processing in the frequency domain, and this is already becoming the standard method of ultrasonic data acquisition in field installations. The method according to the invention can also be performed using software with the data after the scan has been finished, so it has little impact on the initial data scan time for the sample.

Many variations of the method and apparatus described herein are possible within the scope of the invention. For instance, frequency ranges where the recorded power is tainted by surface backscatter can be determined by fitting measured data to formulas based on grating theory, instead of by the empirical determination described above.

The composite power spectrum used to determine the tainted frequency ranges can be based on data from all the measured scan sites when a complete set of data is recorded, and the Integrated Polar Backscatter can be calculated from the recorded data base. Alternatively, data from only a few selected scan sites can first be used to determine the excluded frequency ranges, and a full set of scans can later be taken, with each pixel immediately being identified as either good or bad as the scan is progressing.

It would also be possible to do the summation for the composite power spectrum in the logarithmic domain, instead of in the linear domain. Because of the signal compression that the logarithmic values represent, this would improve the signal to noise ratio. It would, however, be necessary to convert the composite power data to linear values before further calculations to determine the frequency ranges to be excluded.

Numerous further modifications and adaptations of the present invention will become apparent to those skilled in the art. Thus, the following claims are intended to cover all such modifications and adaptations which fall within the true spirit and scope of the present invention.

What is claimed is:

Claims

1. A method for non-destructive evaluation of composite materials with surface impressions, comprising the steps of:

(a) insonifying a series of scan sites on a composite material sequentially with ultrasound at a fixed polar angle larger than zero and a fixed azimuthal angle;

(b) calculating a power spectrum for the polar backscatter for each said scan site;

(c) adding the measured backscatter power spectra from several of said scan sites to form a composite power spectrum for polar backscatter;

(d) identifying frequency ranges in said composite power spectrum where significant peaks occur;

(e) eliminating said identified frequency ranges from each recorded frequency spectrum for scan sites of the composite material; and

(f) integrating the remaining power spectrum for each said scan site to obtain a value for Integrated Polar Backscatter for each said scan site substantially free from errors caused by impressions on the surface of the composite material.

2. A method for non-destructive evaluation of composite materials with surface impressions according to claim 1, wherein step (d) comprises the sub-steps of:

smoothing the frequency power spectrum;

plotting the first derivative of said smoothed power spectrum with respect to frequency;

determining the frequencies where said first derivative has zero values;

determining frequencies where said first derivative has peaks and valleys adjacent to said frequencies corresponding to zero values;

determining the amplitude values for said peaks and valleys;

plotting straight lines intersecting said composite power spectrum at each of said frequencies corresponding to peaks and valleys in the first derivative plot and having slopes equal to said amplitudes of corresponding said peaks and valleys;

determining where said straight lines intersect the frequency axis of said composite spectrum; and

defining a peak area as the frequency range between said intersections of a pair of adjacent straight lines spanning a frequency where said first derivative has a zero value.

3. A method for non-destructive evaluation of composite materials with surface impressions according to claim 1, wherein step (d) comprises the sub-steps of:

determining the total maximum and the total minimum amplitude in the composite power spectrum, and calculating the difference therebetween;

determining the differences between peaks and minima for individual peaks in the composite power spectrum;

dividing the difference between peak and minimum for each individual peak by the difference between the total maximum and the total minimum and recording the quotient for each division; and

designating as significant those peaks having a said quotient exceeding a predetermined threshold value.

4. Apparatus for non-destructive evaluation of the interior of composite materials with surface impressions, comprising:

(a) a broadband ultrasonic transducer in pulse echo mode focused at a test site on the surface of a composite material at a non-normal angle of incidence, and means for causing a wave front to be emitted from said transducer;

(b) amplifying means for amplifying time domain signals from said transducer during predetermined gating intervals;

(c) converting means for converting the amplified time domain signals to a power spectrum in the frequency domain;

(d) means for detecting peaks in the power spectrum;

(e) means for identifying frequency ranges associated with the peaks;

(f) means for summing frequencies excluding the identified frequency ranges to obtain a net sum of frequencies;

(g) means for integrating the power spectrum over frequency ranges excluding the identified frequency ranges to obtain a net value for total energy;

(h) means for calculating the quotient of the net total energy and the net sum of frequencies to obtain a quantity known as Integrated Polar Backscatter; and

(i) means for comparing the integrated Polar Backscatter with a reference value to determine if the Integrated Polar Backscatter represents a defective composite material.

5. Apparatus for non-destructive evaluation of the interior of composite materials with surface impressions according to claim 4, wherein said converting means is an analog spectrum analyzer.

6. Apparatus for non-destructive evaluation of the interior of composite materials with surface impressions according to claim 4, wherein said converting means is a digital computer programmed to perform Fourier transforms.

7. Apparatus for non-destructive evaluation of the interior of composite materials with surface impressions according to claim 4, wherein a digital computer is programmed to serve as (d) means for detecting peaks in the power spectrum, (e) means for identifying frequency ranges associated with the peaks, (f) means for summing frequencies excluding the identified frequency ranges to obtain a net sum of frequencies, (g) means for integrating the power spectrum over frequency ranges excluding the identified frequency ranges to obtain a net value for total energy, (h) means for calculating the quotient of the net total energy and the net sum of frequencies to obtain a quantity known as Integrated Polar Backscatter, and (i) means for comparing the integrated Polar Backscatter with a reference value to determine if the Integrated Polar Backscatter represents a defective composite material.

8. A method to correctly compute the quantity known as integrated polar backscatter when applied to composite materials with surface impressions, comprising the steps of:

(a) insonifying an area of a composite material with ultrasound at a fixed polar angle larger than zero and a fixed azimuthal angle;

(b) recording a frequency spectrum of the polar backscatter power for the area;

(c) identifying frequency ranges in the composite spectrum where significant peaks occur;

(d) recording a frequency spectrum for a scan site of the composite material;

(e) eliminating the identified frequency ranges from the recorded frequency spectrum for the scan site; and

(f) calculating a value for the Integrated Polar Backscatter for the remaining frequency spectrum for the scan site.

9. A method to correctly compute the quantity known as integrated polar backscatter when applied to composite materials with surface impressions according to claim 8, wherein step (c) comprises the sub-steps of:

smoothing the frequency spectrum of the backscatter power;

plotting the first derivative of the smoothed spectrum with respect to frequency;

determining the frequencies where the first derivative has zero values;

determining frequencies where the first derivative has peaks and valleys adjacent to the zero value;

determining the amplitude values for the peaks and valleys;

plotting straight lines intersecting the composite power spectrum at each of the frequencies corresponding to peaks and valleys in the first derivative plot and having slopes equal to the amplitudes of the corresponding peaks and valleys;

determining where the straight lines intersect the abscissa of the composite power spectrum; and

defining a peak area as the frequency range between the intersections of a pair of adjacent straight lines spanning a frequency where the first derivative has a zero value.

10. A method to correctly compute the quantity known as integrated polar backscatter when applied to composite materials with surface impressions according to claim 8, wherein step (c) comprises the sub-steps of:

determining the total maximum and the total minimum amplitude in the composite power spectrum, and calculating the difference therebetween;

determining the differences between peaks and minima for individual peaks in the composite power spectrum;

dividing the difference between peak and minimum for each individual peak by the difference between the total maximum and the total minimum and recording the quotient for each division; and

designating as significant those peaks having a quotient exceeding a predetermined threshold value.

METHOD AND APPARATUS FOR NON-DESTRUCTIVE EVALUATION OF COMPOSITE MATERIALS WITH CLOTH SURFACE IMPRESSIONS

Abstract of the Disclosure

A method and related apparatus for non-destructive evaluation of composite materials by determination of the quantity known as Integrated Polar Backscatter, which avoids errors caused by surface texture left by cloth impressions by identifying frequency ranges associated with peaks in a power spectrum for the backscattered signal, and removing such frequency ranges from the calculation of Integrated Polar Backscatter for all scan sites on the composite material.

APPENDIX A

"Measured Effects of Surface Cloth Impressions on Polar Backscatter and Comparison With a Reflection Grating Model"

Madaras et al., 19th Annual Review of Progress in Quantitative Nondestructive Evaluation, July 20-24, 1992, La Jolla, CA, USA

MEASURED EFFECTS OF SURFACE CLOTH IMPRESSIONS ON POLAR BACKSCATTER AND COMPARISON WITH A REFLECTION GRATING MODEL

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INTRODUCTION

Integrated polar backscatter has been shown to have potential applications to composites, especially for the detection of matrix cracking, delaminations, fiber waviness, fiber fracture, inclusions and porosity [1-11]. The method was attractive because it avoided several measurement limitations inherent to conventional pulse echo techniques. Polar backscatter, however, has not been without its disadvantages. It has been reported that surface texture introduces unwanted artifacts in images made using the polar backscatter method [12]. One suggested method to overcome this limitation was the use of stripable coatings, which are paints that approximately match the impedance of the composite surface and have the effect of physically "smoothing" the surface impressions away [13]. After ultrasonic testing, these paints can be removed, but this method entails additional part handling and increases the cost of production.

The purpose of this paper is to address the nature of a typical composite surface and its effects on scattering. Once an understanding of the source of the signal artifacts is reached, more attractive methods may be developed to overcome the current limitations of the method.

Using epoxy typical of that in composites and standard composite fabrication techniques we produced a sample with release cloth impressions on its surface. A simple model for the scattering from the surface impressions of this sample was then constructed and finally, polar backscatter measurements were made on the sample and compared with the predictions of the model.

THEORY

In polar backscatter, the sound insonifies the surface at an angle θ with respect to the surface normal. On a composite surface which has a fabric impression, the surface profile will modulate the angle θ so that specific locations are nearly perpendicular to the direction of the insonification and reflect the sound back onto the transducer. To model the surface, consider Figure 1 which shows a microscopic image of the surface of the panel used in this study. The surface impressions were formed by a teflon coated fabric (4 harness weave, 60 threads per inch). Figure 2a shows an acoustic microscope image from the panel in which the fill fibers run horizontally and the warp fibers run vertically. Figure 2b shows the profile of the surface which corresponds to the horizontal line located in the middle of Figure 2a. This pattern indicates a regularly repeated sequence which can be modeled as a series of planar reflectors as illustrated in Figure 3. This pattern represents a one dimensional reflection grating that will produce interference effects at the measuring transducer. In order to predict the interference effects, the phase relationship of the system of reflectors must be generated. Based on Figure 3, the following equation for the power is derived:

$$|E(f)|^2 = |E_o(f)|^2 M^2 \chi(R, A, a, b) \left\{\frac{\sin([N+1]\xi)}{\sin(\xi)}\right\}^2 \left\{\frac{\sin(4\eta)}{\sin(\eta)}\right\}^2 \left\{\frac{\sin(2\gamma)}{\sin(\gamma)}\right\}^2. \quad (1)$$

In this equation, $|E(f)|^2$ is the reflected signal power, f is the frequency, and $E_o(f)$ is the incident signal amplitude. χ (R, A, a, b) is a function that depends of the reflection coefficient, R, the total area insonified, A, the reflector width, a, in the x direction and the reflector width, b, in the y direction. (For simplification, we have assumed that the two reflectors indicated in Figure 3 are of equal width, $a_1 = a_2 = a$.) M is the number of repeated patterns in the y direction within the beam. N is the number of repeated patterns in the x direction within the beam. (The number of fibers in the repeat pattern in both directions is 4 threads.) The phase terms ξ, γ, and η are defined by:

$$\xi = k\, p \sin(\theta), \quad (2a)$$

$$\gamma = k\, g \sin(\theta), \quad (2b)$$

and

$$\eta = k\, h \sin(\theta), \quad (2c)$$

where k is the wave number of the ultrasound in the coupling media (water), p is the distance between reflectors denoted by a_1 in Figure 3, and g is the distance between the reflectors a_1 and a_2 in Figure 3. The adjacent rows have a similar pattern, except that they are offset by a distance h from our reference point, x = 0. It can be seen from Figure 2a that h = p/4.

Eq. 1, in general, will produce narrow peaks in its spectrum that represent the effects of the surface impressions. Two additional improvements to this model can be made by allowing variation of reflector locations from the idealized patterns and accounting for the frequency dependence of the beam width.

It should be expected that the locations of the individual threads in the fabric which led to the surface impressions will vary somewhat from the idealized pattern we have defined. By assuming a distribution for the location of the reflection points, we can include the effects of the variability of the thread locations within the beam area. For each reflector in the pattern, a Gaussian-like distribution centered about the ideal reflector location was assumed where the normal variance term, σ, was adjusted for each reflector to be $\kappa \sqrt{x_0}$. The symbol κ is a constant variance which is scaled by the square root of the idealized distance of the reflector away from the origin, $\sqrt{x_0}$. (i.e., the farther from the x = 0 point, the larger the variance.) Other dependencies were investigated but this functional form provided the best fit with the measured data.

The other improvement in this model is obtained by the inclusion of a frequency dependent beam width effect. Most calibration methods only calibrate the total energy incident on

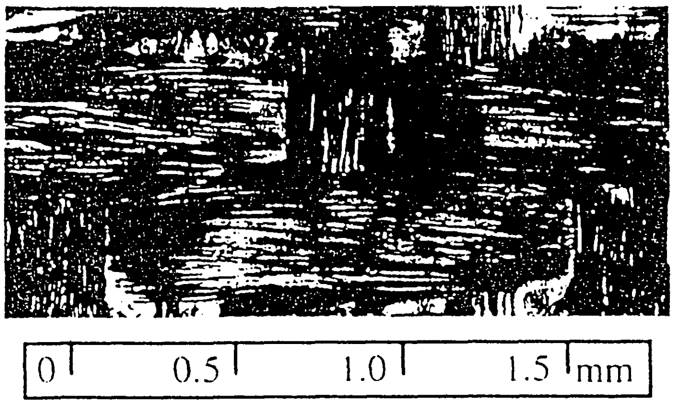
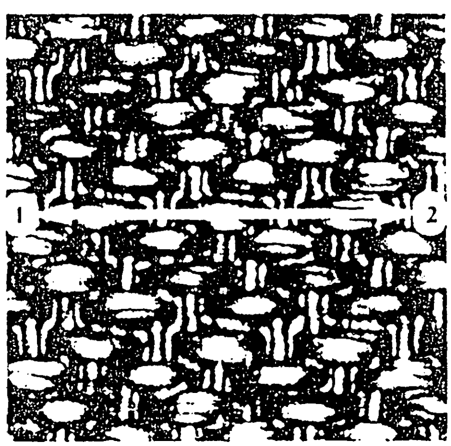


Figure 1. A microphotograph of the surface of the sample. The image is 2 mm wide.

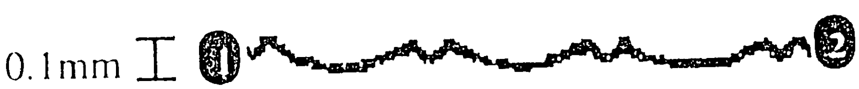
the part and ignore the beam width geometry. Of course, as the ultrasound frequency is increased, the beam width becomes smaller and the insonifying power per unit area will increase. This effect can be accounted for in our model by using a frequency dependent beam area, A, and frequency dependent numbers of reflection points, N and M. We can approximate the beam area as the area of the beam generated by a planar transducer out to the first diffraction minimum, or $\pi r_x r_y$, where r_x is the beam radius in the x direction, and r_y is the beam radius in the y direction. This approximation is used to generate estimates for N and M,

$$N(f) = r_x(f) / p \tag{3a}$$

and



a)



b)

Figure 2. a) An ultrasonic microscope image of the surface of the sample shown in fig. 1. The view shows a 6 mm by 6 mm area of the sample surface. b) The surface profile along the marker shown in figure 2a.

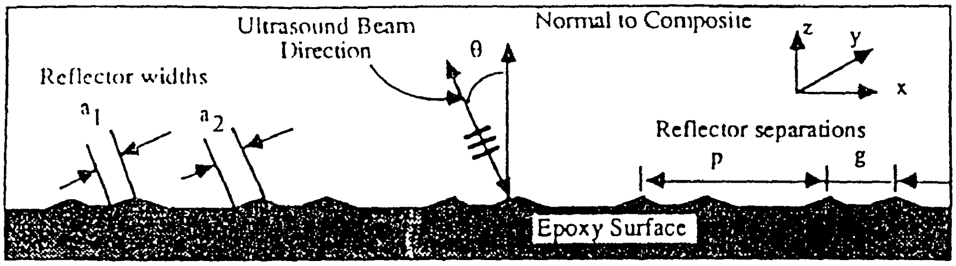


Figure 3. A simple model of the cross-section of the surface of a composite with cloth surface impressions corresponding to fig. 2b.

$$M(f) = r_y(f) / 4b. \qquad (3b)$$

By including probability distributions for the reflector positions and the effects of a frequency dependent beam area, Eq. 1 can be amended to the following form:

$$\frac{|E(f)|^2}{|E_0(f)|^2} = \frac{M^2 \chi_B(R, a, b)}{\pi r_x r_y} e^{-4\kappa^2(N\xi_0 + 3\eta_0 + \gamma_0)} \times \left\{\frac{\sin^2((N+1)\xi_0) + \sinh^2(2(N+1)\kappa^2\xi_0)}{\sin^2(\xi_0) + \sinh^2(2\kappa^2\xi_0)}\right\} \times \left\{\frac{\sin^2(4\eta_0) + \sinh^2(8\kappa^2\eta_0)}{\sin^2(\eta_0) + \sinh^2(2\kappa^2\eta_0)}\right\}\left\{\cos^2(\gamma_0) + \sinh^2(2\kappa^2\gamma_0)\right\}. \qquad (4)$$

The function $\chi(R, A, a, b)$ has been replaced by $\chi_B(R, a, b)/\pi r_x r_y$ which allows the frequency dependent beam area to be expressed explicitly. The terms ξ_0, γ_0, and η_0, which are the average values of ξ, γ, and η, can be estimated by the dimensions of the weave and Eq. 2. Estimates of N and M can be made by using Eq. 3 and theoretical values for the beam dimensions. The function $\chi_B(R, a, b)$ can be treated as a general constant in the fitting equation. The parameters in this equation can be determined by applying nonlinear fitting routines to the data.

EXPERIMENTAL METHODS

Specimen

The samples used in this study were fabricated at NASA Langley Research Center. They consisted of two plates that were 6" by 6" by 1/8" made from type 3501-6 epoxy which is commonly used in making composite materials. Both samples underwent handling and cure cycles identical to standard composite manufacturing practices. One was made with release cloth impressions on both sides while a control sample was made with smooth surfaces.

Anisotropy Measurements

Measurements of the anisotropy of integrated polar backscatter were performed using a broad band 5 MHz center frequency, 0.5" diam., 4" focus, immersible transducer in pulse echo mode (Figure 4). Data were obtained for polar angles (θ) of 10^o, 20^o, and 30^o with the focal region of the transducer placed at the top surface of the sample. The apparent anisotropy produced by the surface features of the epoxy was investigated by varying the azimuthal angle of insonification in one degree increments. (An azimuthal angle $\phi = 0^o$ corresponded to the warp direction of the cloth impressions.) At each angle, ϕ, data were collected across a 3 by 3 array (1 mm between points) to obtain spatial averaging. The received backscattered rf signal was amplified (Metrotek MR 106), passed through a 5 μs

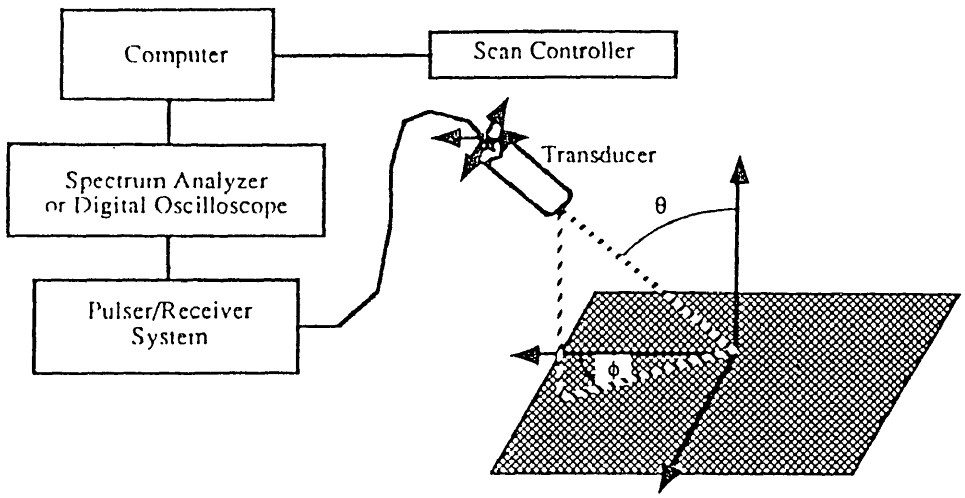


Figure 4. Experimental equipment set up

Metrotek MG 701 stepless gate (beginning slightly before the first reflection) and sent into a Hewlett Packard 8557A analog spectrum analyzer. The power spectrum obtained at each site was normalized by the power spectrum corresponding to the specular echo from a polished stainless steel plate. Finally, the mean (spatially averaged) normalized spectrum at each azimuthal angle, ϕ, was obtained and frequency averaged across the useful bandwidth (3 to 7 MHz) yielding the integrated backscatter (Figure 5)

Spectral Analysis Measurements

Spectral analysis measurements were performed using the same geometric configuration as described above, but the azimuthal angle was fixed at $\phi = 90°$ for all scans. C-scans with the polar angle held constant at 10°, 20°, and 30° in turn, were taken while stepping through a 53 by 53 point (5.2 by 5.2 cm) grid. Two experimental arrangements were used to collect and process the data. In one configuration the rf signals were generated and amplified by a pulser/receiver (Metrotek MP215 and MR101), recorded using a digital oscilloscope (LeCroy 9400) sampling at 100 Msamples/sec, and stored in a computer for off-line analysis. The power spectrum corresponding to each digitized rf signal was determined and the spectra from all sites were averaged thus providing a mean spectral response

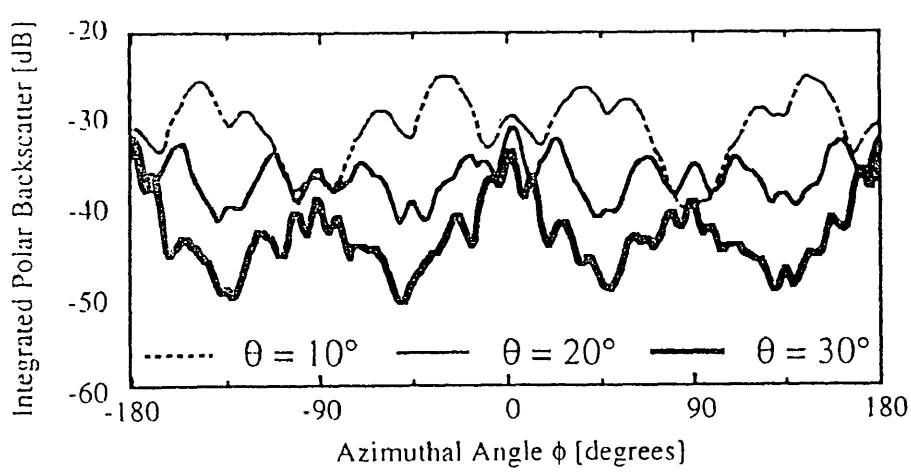


Figure 5. Plot of the Integrated Polar Backscatter vs. azimuthal angle from an epoxy plate with surface impressions for θ = 10°, 20°, and 30°.

characterizing the panel. The mean data were normalized by the spectral response of the system using a planar stainless steel reflector placed in the focal zone of the transducer. Spectral response data were also collected using the amplifier/gate/analog spectrum analyzer arrangement as described in detail in the anisotropy measurements section.

RESULTS

The azimuthal scans illustrate of the severity of the effects of surface impressions. The data from the smooth (control surface) plate were near the noise level of the equipment. Figure 5 shows the integrated polar backscatter (3 to 7 MHz) from the plate with surface impressions versus the azimuthal angle for polar angles of 10^o, 20^o and 30^o. The data exhibit azimuthal variations of 15 to 20 dB integrated backscatter values. Furthermore, in some azimuthal directions the backscatter from the surface would dominate even the high internal scattering from porosity in graphite/epoxy composite as measured in our prior work.

In order to compare the theory with the data, we have plotted frequency dependent data generated from the plate with surface impressions with the most accurate Levenberg-Marquardt algorithm fits to Eq. 4 in Figure 6. The general nature of the data and the relatively accurate fit with our theory are apparent from the figures. Eq. 4 was specifically derived considering the $\phi = 90^o$ direction shown in Figure 2; the resulting fit parameters are shown with their anticipated values in Table I. The fitted values for the parameter p are all in the range of 1.6 to 1.7 mm. corresponding to approximately 60 to 62 threads per inch. The fitted values of h are similar in magnitude (0.41 to 0.43 mm) and also correspond to 60 threads per inch. It is predicted from the weave pattern impressions that h would be 1/4 of p. The values of g range from 0.44 to 0.50. It should be noted that the variable g might deviate slightly from the value of h in the example used here because the exact points on Figure 2b where a reflection might occur could shift as the polar angle changes. Finally, the variable scaling parameter, κ, has a range of about 0.13 to 0.22, which helps to give a measure of the spatial variability of the threads in the fabric.

DISCUSSION

It has previously been noted that the surface texture is a source of additional signal that compromises the quantitative results from integrated polar backscatter. The purpose of this work was to demonstrate the origins of those signals. By modeling the surface as a reflection grating, the general quantitative features of the data were produced. In this model, a simplified beam function was assumed and the variability of the thread impression pattern within the beam pattern was assumed. This model corresponds well with actual physical features present on the surface of the composite.

Based on this work, several improvements can be readily suggested which will enhance the quantitative nature of integrated polar backscatter measurements. One of the simplest would be to lay up the release cloth in a direction where artifacts from the surface reflections would not dominate the desired polar backscatter measurement directions. This fact coupled with a judicious selection of polar angles could lead to adequate sensitivity in spite of the surface complications. The simple scans shown in Figures 5 and 6 would quickly identify the needed orientations. Another practical method would be to use the following equation (described graphically in Figure 7) to limit the frequency regions used for calculation of the integrated backscatter to those which are not dominated by surface reflections.

$$I = \frac{\int_{f_1}^{f_2} |S(f)|^2 df}{f_2 - f_1} + \frac{\int_{f_3}^{f_4} |S(f)|^2 df}{f_4 - f_3} + \dots + \frac{\int_{f_{N-1}}^{f_N} |S(f)|^2 df}{f_N - f_{N-1}}. \qquad (5)$$

Methods such as these would be relatively fast and efficient and avoid the need for special preparations of samples after manufacture.

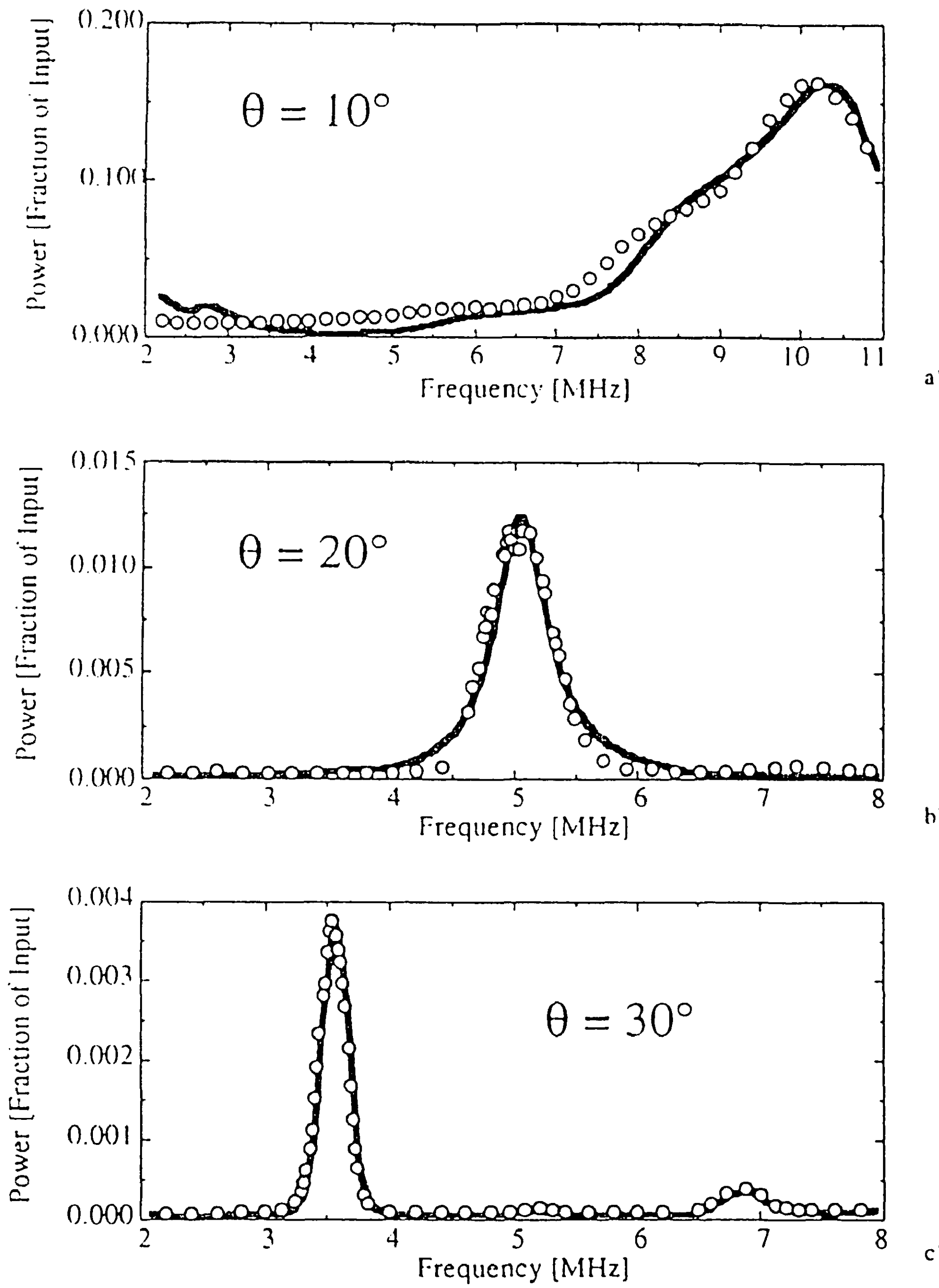


Figure 6. Plots of the polar backscatter power vs. the frequency. The data are shown as circles. The fit is shown as a solid line. a) $\theta = 10^o$. b) $\theta = 20^o$. c) $\theta = 30^o$.

ACKNOWLEDGEMENTS

This work is supported by NASA's Office of Aeronautics and Space Technology, in part by grant NSG 1601.

Table 1: List of Parameter Values Used to Fit the Data in Eq. 4.

Parameters	Anticipated Values	Measured values from: $\theta = 10^o$	$\theta = 20^o$	$\theta = 30^o$
p, the pattern repeat spacing	1.65 mm	1.6 mm	1.7 mm	1.7 mm
g, the distance between two adjacent reflectors	> 0.42 mm	0.50 mm	0.44 mm	0.50 mm
h, the distance between two warp threads	0.42 mm	0.42 mm	0.43 mm	0.41 mm
κ, the variability of the thread locations		0.22 $\sqrt{mm}$	0.16 $\sqrt{mm}$	0.13 $\sqrt{mm}$

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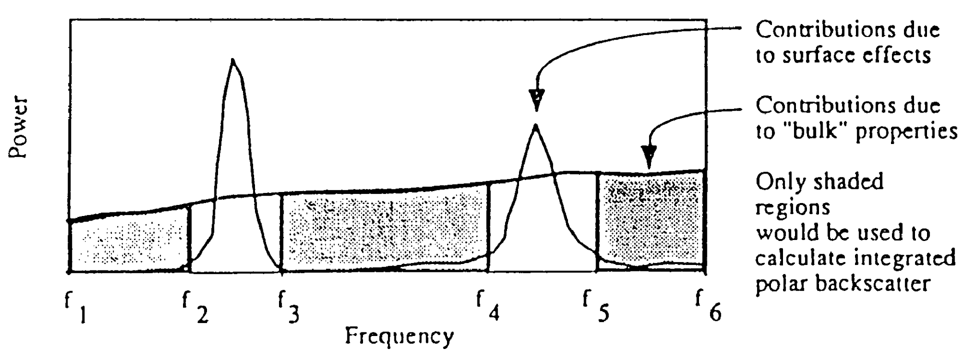


Figure 7. Useful spectral ranges for eq. 5.

FIG. 1(a)

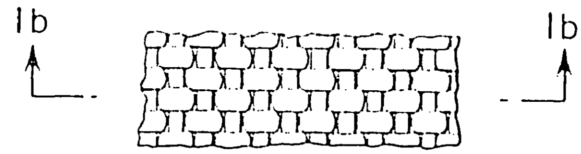


FIG. 1 (b)

FIG. 2

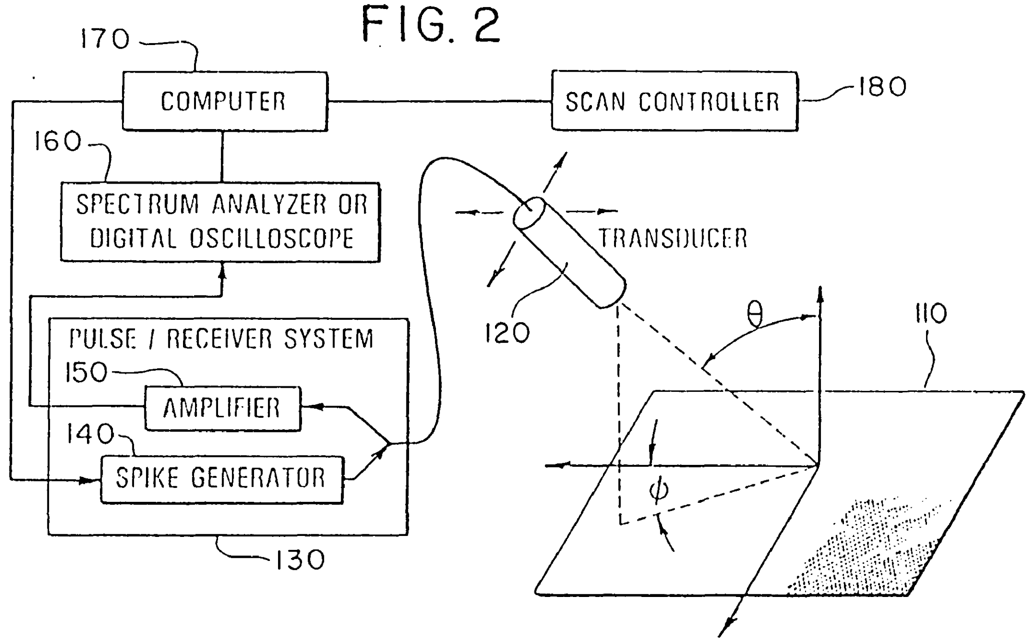


FIG. 4(a)

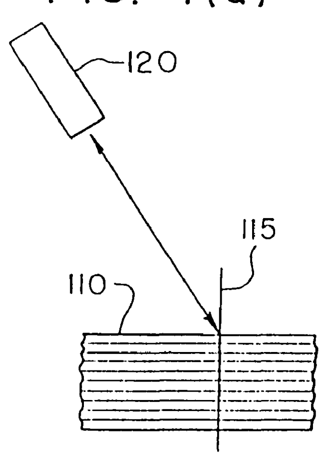


FIG. 4(b)

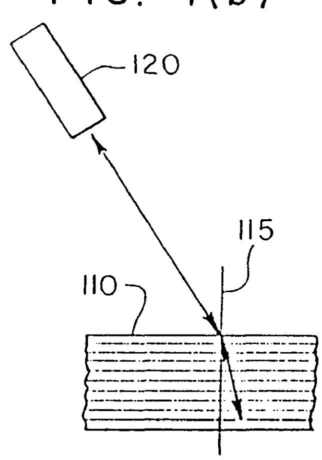


FIG. 4(c)

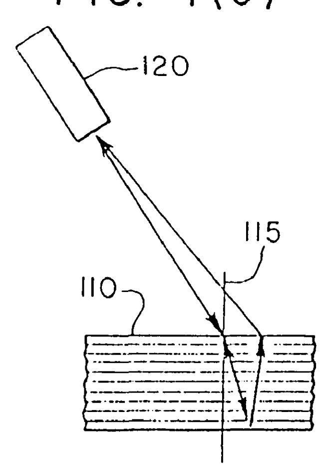


FIG. 3(a)

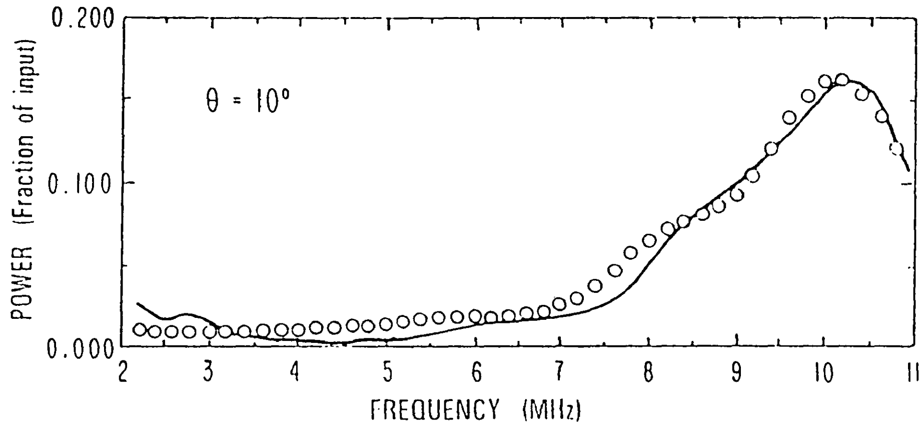


FIG. 3(b)

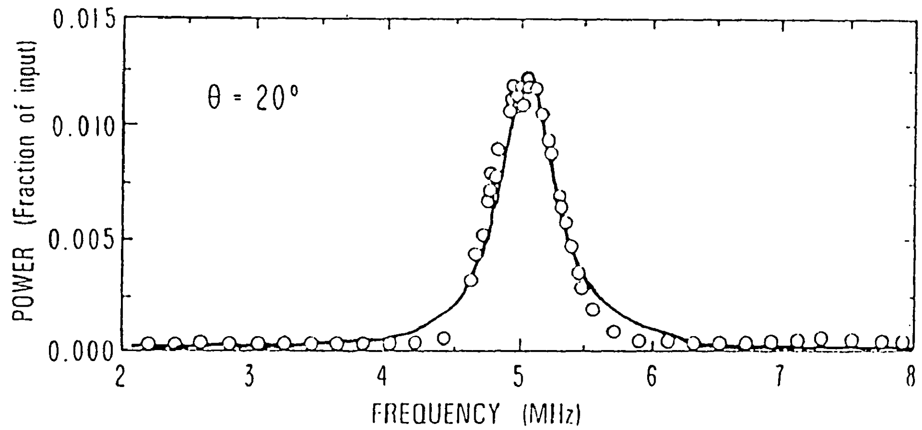


FIG. 3(c)

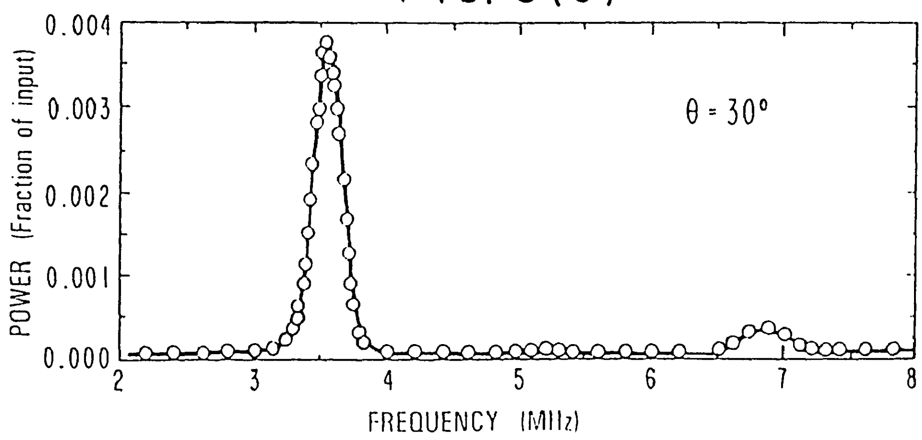


FIG. 5

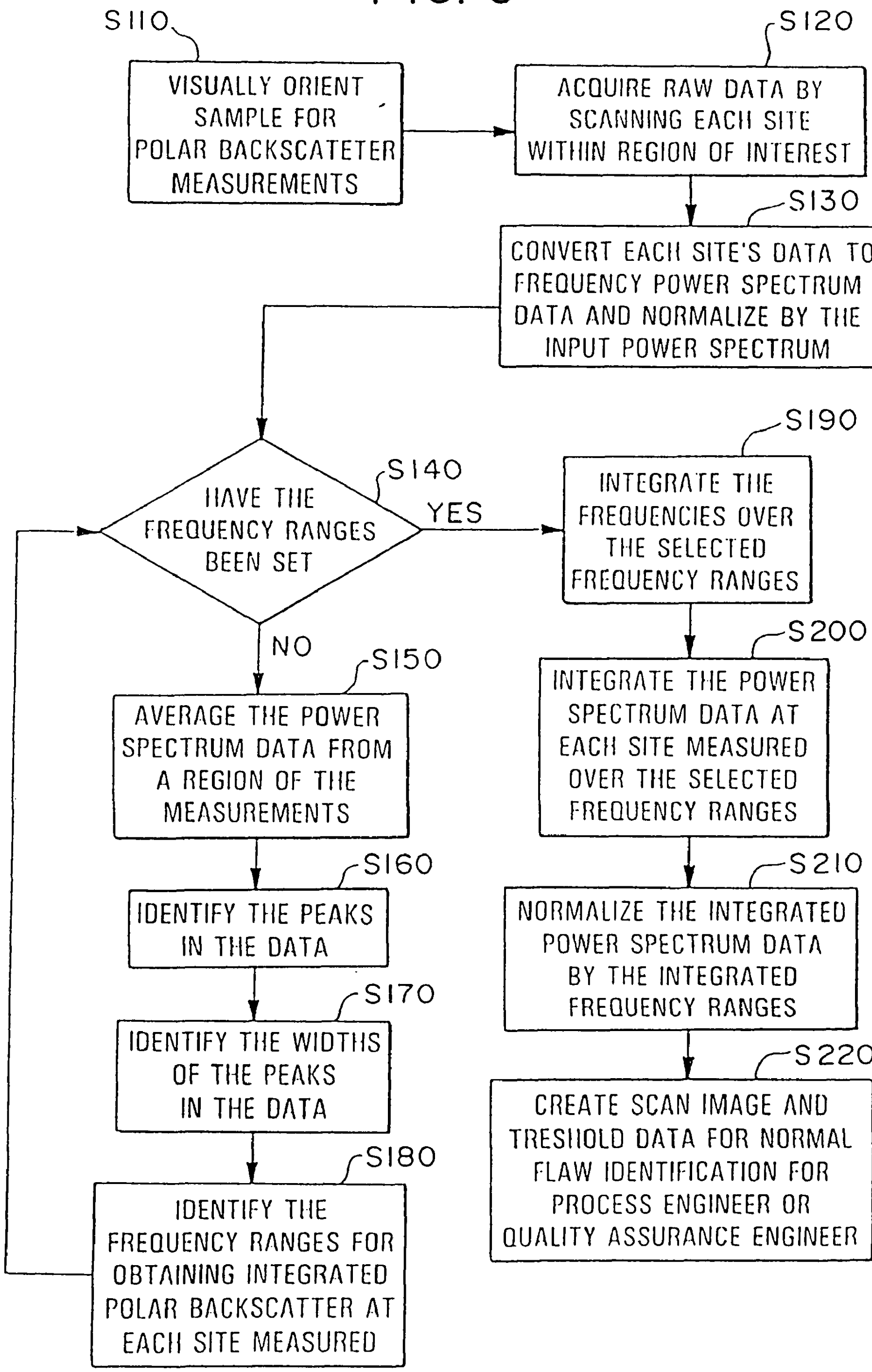

S110
VISUALLY ORIENT SAMPLE FOR POLAR BACKSCATETER MEASUREMENTS
S120
ACQUIRE RAW DATA BY SCANNING EACH SITE WITHIN REGION OF INTEREST
S130
CONVERT EACH SITE'S DATA TO FREQUENCY POWER SPECTRUM DATA AND NORMALIZE BY THE INPUT POWER SPECTRUM
S140
HAVE THE FREQUENCY RANGES BEEN SET
YES
NO
S150
AVERAGE THE POWER SPECTRUM DATA FROM A REGION OF THE MEASUREMENTS
S160
IDENTIFY THE PEAKS IN THE DATA
S170
IDENTIFY THE WIDTHS OF THE PEAKS IN THE DATA
S180
IDENTIFY THE FREQUENCY RANGES FOR OBTAINING INTEGRATED POLAR BACKSCATTER AT EACH SITE MEASURED
S190
INTEGRATE THE FREQUENCIES OVER THE SELECTED FREQUENCY RANGES
S200
INTEGRATE THE POWER SPECTRUM DATA AT EACH SITE MEASURED OVER THE SELECTED FREQUENCY RANGES
S210
NORMALIZE THE INTEGRATED POWER SPECTRUM DATA BY THE INTEGRATED FREQUENCY RANGES
S220
CREATE SCAN IMAGE AND TRESHOLD DATA FOR NORMAL FLAW IDENTIFICATION FOR PROCESS ENGINEER OR QUALITY ASSURANCE ENGINEER

FIG. 6(a)

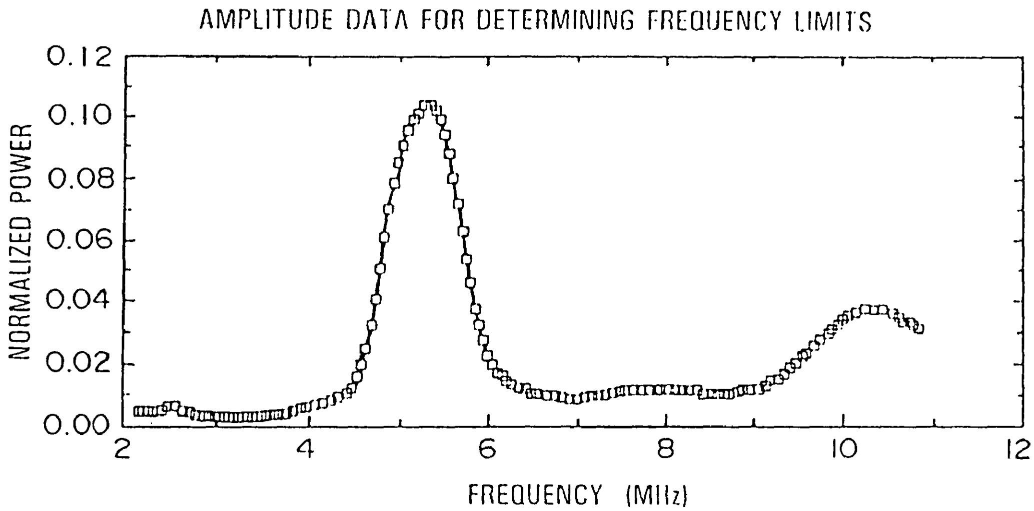

AMPLITUDE DATA FOR DETERMINING FREQUENCY LIMITS
NORMALIZED POWER
0.12
0.10
0.08
0.06
0.04
0.02
0.00
2
4
6
8
10
12
FREQUENCY (MHz)

FIG. 6(b)

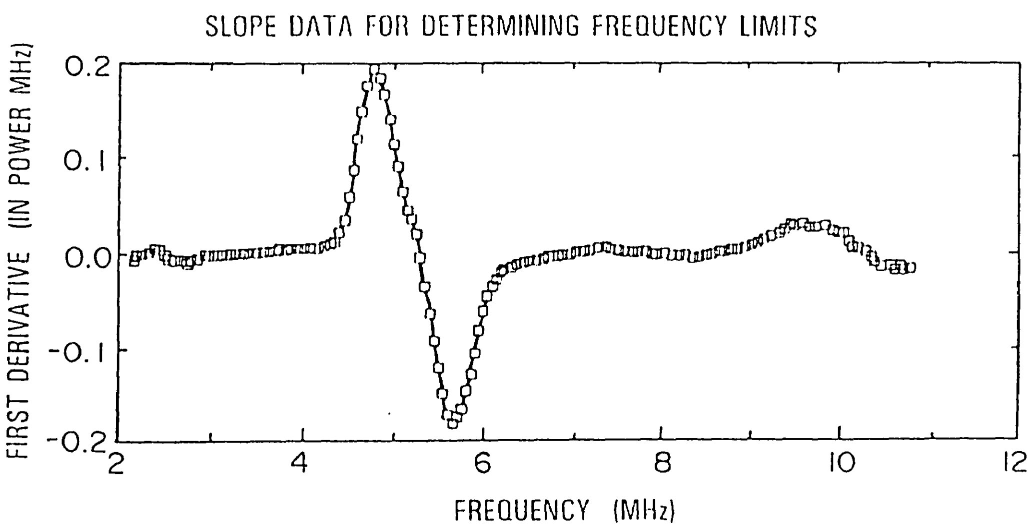

SLOPE DATA FOR DETERMINING FREQUENCY LIMITS
FIRST DERIVATIVE (IN POWER MHz)
0.2
0.1
0.0
-0.1
-0.2
2
4
6
8
10
12
FREQUENCY (MHz)

FIG. 6(c)

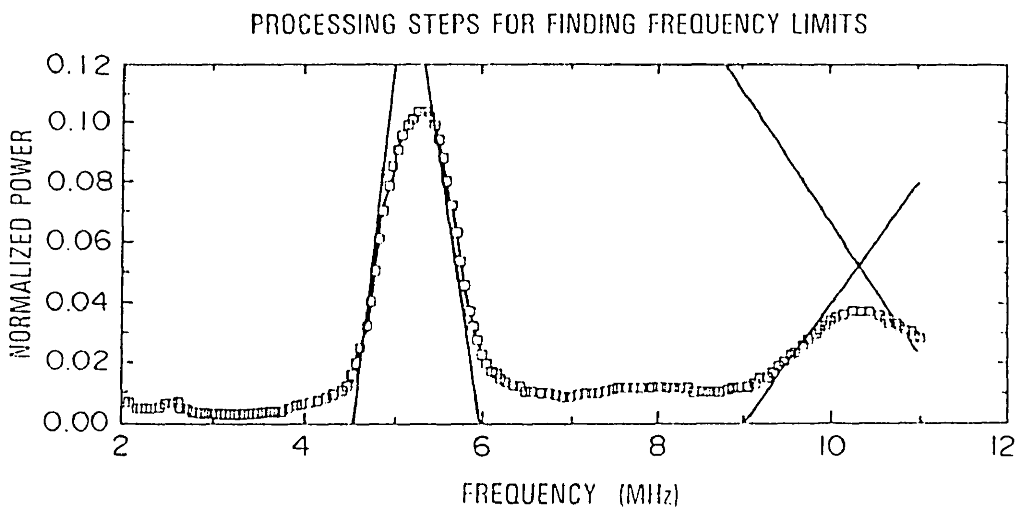
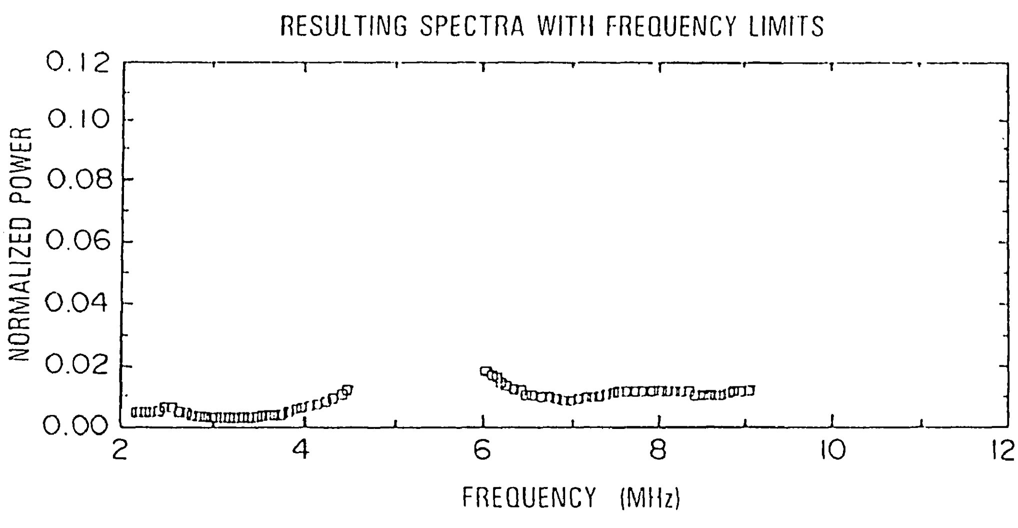

PROCESSING STEPS FOR FINDING FREQUENCY LIMITS
NORMALIZED POWER
0.12
0.10
0.08
0.06
0.04
0.02
0.00
2
4
6
8
10
12
FREQUENCY (MHz)

FIG. 6(d)


RESULTING SPECTRA WITH FREQUENCY LIMITS
NORMALIZED POWER
0.12
0.10
0.08
0.06
0.04
0.02
0.00
2
4
6
8
10
12
FREQUENCY (MHz)

Surf. [illegible] 1/3/93

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SERIAL NUMBER	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.
08/110,278	07/16/93	NAGARAS	

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ART UNIT	PAPER NUMBER
2505	4

DATE MAILED: [illegible]

This is a communication from the examiner in charge of your application.
COMMISSIONER OF PATENTS AND TRADEMARKS

☒ This application has been examined ☐ Responsive to communication filed on ________ ☐ This action is made final.

A shortened statutory period for response to this action is set to expire 3 month(s), — days from the date of this letter.
Failure to respond within the period for response will cause the application to become abandoned. 35 U.S.C. 133

Part I THE FOLLOWING ATTACHMENT(S) ARE PART OF THIS ACTION:

1. ☒ Notice of References Cited by Examiner, PTO-892.
2. ☒ Notice of Draftsman's Patent Drawing Review, PTO-948.
3. ☒ Notice of Art Cited by Applicant, PTO-1449.
4. ☐ Notice of Informal Patent Application, PTO-152.
5. ☐ Information on How to Effect Drawing Changes, PTO-1474.
6. ☐ ________

Part II SUMMARY OF ACTION

1. ☒ Claims 1 to 10 are pending in the application.

   Of the above, claims ________ are withdrawn from consideration.

2. ☐ Claims ________ have been cancelled.
3. ☐ Claims ________ are allowed.
4. ☒ Claims 1 to 10 are rejected.
5. ☐ Claims ________ are objected to.
6. ☐ Claims ________ are subject to restriction or election requirement.
7. ☐ This application has been filed with informal drawings under 37 C.F.R. 1.85 which are acceptable for examination purposes.
8. ☐ Formal drawings are required in response to this Office action.
9. ☐ The corrected or substitute drawings have been received on ________. Under 37 C.F.R. 1.84 these drawings are ☐ acceptable; ☐ not acceptable (see explanation or Notice of Draftsman's Patent Drawing Review, PTO-948).
10. ☐ The proposed additional or substitute sheet(s) of drawings, filed on ________, has (have) been ☐ approved by the examiner; ☐ disapproved by the examiner (see explanation).
11. ☐ The proposed drawing correction, filed ________, has been ☐ approved; ☐ disapproved (see explanation).
12. ☐ Acknowledgement is made of the claim for priority under 35 U.S.C. 119. The certified copy has ☐ been received ☐ not been received ☐ been filed in parent application, serial no. ________ ; filed on ________.
13. ☐ Since this application apppears to be in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under Ex parte Quayle, 1935 C.D. 11; 453 O.G. 213.
14. ☐ Other

BM
DEC 22
PATENT COUNSEL

EXAMINER'S ACTION

PTOL-326 (Rev. 2/93)

Part III DETAILED ACTION

1. The attempt to incorporate subject matter into this application by reference to paper titled "Measured Effects of Surface Cloth Impressions on Polar Backscatter and Comparison with a Reflection Grating Model" is improper because an application may incorporate "essential material" by reference to (1) a US patent, or (2) an allowed US application, MPEP 608.01(p).

Claim Rejections - 35 USC § 101

2. 35 U.S.C. § 101 reads as follows:

> "Whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter or any new and useful improvement thereof, may obtain a patent therefore, subject to the conditions and requirements of this title".

Claims 1 to 10 are rejected under 35 U.S.C. § 101 because the claimed invention is directed to non-statutory subject matter.

A. The basis of this rejection is set forth in the two-step Freeman test given by In re Freeman, 197 USPQ 464 (CCPA 1978), as modified by In re Walter, 205 USPQ 397 (CCPA 1980), and In re Abele, 214 USPQ 682 (CCPA 1982). See In re Meyer, 215 USPQ 193, 198 (CCPA 1982).

MEANS-PLUS FUNCTION CLAIM LANGUAGE

B. Claims 4 to 7 are written in means-plus-function format and for the purpose of this rejection are being treated as though they are method claims. The courts have held that such treatment is acceptable:

"If the functionally-defined disclosed means and their equivalents are so broad that they encompass any and every means for performing the recited functions, the apparatus claim is an attempt to exalt form over substance since the claim is really to the method or series of functions itself. In computer-related inventions, the recited means often performs the function of "number crunching" (solving mathematical algorithms and making calculations). In such cases the burden must be placed on the applicant to demonstrate that the claims are truly drawn to specific apparatus distinct from other apparatus capable of performing the identical functions.

If this burden has not been discharged, the apparatus will be treated as if it were drawn to the method or process which encompasses all of the claimed "means".

See In re Walter, 205 USPQ 397, 408 (CCPA 1980) and In re Abele, 214 USPQ 682, 688 (CCPA 1982).

C. In re Freeman, 197 USPQ 464 (CCPA 1978), first established a "two part" test for determining whether a claim "passes muster" under 35 USC 101. The first part in the Freeman test is to determine whether an algorithm is either directly or indirectly claimed. The second part is to further analyze the claim to ascertain whether in its entirety it wholly pre-empts that algorithm. In re Walter, 205 USPQ 397, 407 (CCPA 1980) defined the second part of the test as follows:

> **"If it appears that the mathematical algorithm is implemented in a specific manner to define structural relationships between the physical elements of the claim (in apparatus claims) or to refine or limit claim steps (in process claims), the claim being otherwise statutory, the claim passes muster under 101. If, however, the mathematical algorithm is merely presented and solved by the claimed invention, as was the case in Benson and Flook, and is not applied in any manner to physical elements or process steps, no amount of post-solution activity will render the claim statutory; nor is it saved by a preamble merely reciting the field of use of the mathematical algorithm."**

In In re Abele, 214 USPQ 682, 686 (CCPA 1982), the CCPA further modified the second part of the test to provide a more comprehensive test:

> **"Appellants summarize the Walter test as setting forth two ends of a spectrum: what is now clearly nonstatutory, i.e., claims in which an algorithm is merely presented and solved by the claimed invention (preemption), and what is**

clearly statutory, i.e., claims in which an algorithm is implemented in a specific manner to define structural relationships between the physical elements of the claim (in an apparatus claim) or to refine or limit steps (in a process). Appellants urge that the statement of the test in Walter fails to provide a useful tool for analyzing claims in the "gray area" which falls between the two ends of that spectrum. We agree that the board's understanding and application of the Walter analysis justifies appellant's position. However, the Walter analysis quoted above does not limit patentable subject matter only to claims in which structural relationships or process steps are defined, limited or refined by the application of the algorithm. Rather, Walter should be read as requiring no more than that the algorithm be "applied in any manner to physical elements or process steps," provided that its application is circumscribed by more than a field of use limitation or non-essential post-solution activity. Thus, if the claim would be "otherwise statutory," id., albeit inoperative or less useful without the algorithm, the claim likewise presents statutory subject matter when the algorithm is included. This broad reading of Walter, we conclude, is in accord with the Supreme Court decisions."

FIRST STEP OF THE FREEMAN TEST

D. The first step of determining the Freeman-Walter-Abele test is to determine whether the claims directly or indirectly recite a mathematical algorithm.

By applying the first step of the Freeman-Walter-Abele test in accordance with M.P.E.P. 2106, one can see that the indicated claims recite a mathematical algorithm.

Claims 1 to 10 indirectly recite calculating a power spectrum, adding the measured backscatter, identifying frequency ranges where significant peaks occur, eliminating identified frequency ranges and integrating, smoothing, plotting to determine when first derivatives are zero, peaks and valleys, slopes, and peak area, calculating the difference between total maximum and total minimum amplitude, and dividing, Fourier transformations, which forms an mathematical algorithm for calculation of the Integrated Polar Backscatter.

SECOND STEP OF THE FREEMAN TEST

E. Once the first step of the Freeman-Walter-Abele test is met, the second part of the Freeman test is to further analyze the claim to ascertain whether the claim in its entirety, wholly pre-empts a mathematical algorithm, In re Abele, 214 USPQ 682, 685 (CCPA 1982), as supported by In re Iwahashi, 12 USPQ 2d 1908, 1911 (CAFC 1989) and In re Grams, 12 USPQ 2d 1824, 1827 (CAFC 1989).

Under In re Abele, 214 USPQ 682,686, (CCPA 1982) we view the claim without the mathematical algorithm to identify the underlying process steps or physical elements to which the mathematical algorithm is applied. "[I]f the claim would be "otherwise statutory," id., albeit inoperative or less useful without the algorithm, the claim likewise presents statutory subject matter when the algorithm is included." Note, however, the fact that a step is physical does not necessarily mean the claim is directed to statutory subject matter. See In re Grams, 12 USPQ 2nd 1824,1827 n.4 Fed. Cir.) (step of performing clinical tests on individuals is considered to mere data gathering). Applicant is asked to point out the underlying process steps or physical elements to which the mathematical algorithm is applied.

In order to make this determination, the claims should be viewed without the mathematical algorithm to determine if what remains is otherwise statutory (In re Abele, 214 USPQ 682, 686 and In re Grams, 12 USPQ 2d 1824, 1827).

Taking each claim as a whole, we have the following:

(1) a field of use limitation

(2) data gathering

(3) post-solution activity.

FIELD OF USE LIMITATIONS

F. "Field of use" or "end use" limitations have been held to be insufficient to constitute a statutory method or process.

The Supreme Court has held that a field of use limitation cannot by itself make a claim statutory by "attempting to limit the use of the formula to a particular technological environment." Diamond v. Diehr, 450 U.S. 175, (1981), 209 USPQ 1,10 (S Ct 1981).

G. The preamble of claims 1 to 3 "A method for non-destructive evaluation of composite materials with surface impressions", "Apparatus for non-destructive evaluation of composite materials with surface impressions", and "A method to correctly compute the quantity known as integrated polar backscatter when applied to composite materials with surface impressions" sets forth a field of use for the mathematical algorithm which attempts to limit the use of the algorithm to a particular environment. As pointed out in In re Walter, 205 USPQ 397 (CCPA 1980), when the mathematical algorithm is merely presented and solved by the claimed invention, field of use limitations are not sufficient to render the claim statutory.

DATA GATHERING LIMITATIONS

H. As to the data gathering, that is, providing data needed by the algorithm, the court has held that:

Claimed steps which "merely determine values for the variables used in the mathematical formulae used in making the calculation" may be insufficient to change a nonstatutory method of calculation into a statutory process. As stated in In re Sarker, 200 USPQ 132,139; (CCPA 1978):

> **"No mathematical equation can be used, as a practical matter, without establishing and substituting values for the variables expressed therein. Substitution of values dictated by the formula has thus been viewed as a form of mathematical step. If the steps of gathering and substituting values were alone sufficient, every mathematical equation, formula, or algorithm having any practical use would be per se subject to patenting as a "process" under <185> 101. Consideration of whether the substitution of specific values is enough to convert the disembodied ideas present in the formula into an embodiment of those ideas, or into an application of the formula, is foreclosed by the current state of law."**

See also, In re Richman, 195 USPQ 340 (CCPA 1977); In re Grams, 12 USPQ2d 1824 <R> (Fed. Cir. 1989).

Further clarification concerning data gathering steps can be found in In re Christensen 178 USPQ 35,37-38 (CCPA 1973):

> **"Given that the method of solving a mathematical equation may not be the subject of patent protection, it follows that the addition of the old and necessary antecedent steps of establishing values for the variables in the equation cannot**

> **convert the unpatentable method to patentable subject matter."**

In re Richman,195 USPQ 340,343 (CCPA 1977) and In re Meyer 215 USPQ 193, 195 (CCPA 1982), states:

> **"In the present case too, notwithstanding that the antecedent steps are novel and unobvious, they merely determine values for the variables used in the mathematical formulae used in making the calculations. Thus, such antecedent steps do not suffice to render the claimed methods, considered as a whole, statutory subject matter."**

END PRODUCT

I. The output or end product of the invention of Claims 1 to 3 and 8 to 10 is simply a number. If the end product of a claimed invention is a pure number, the invention is nonstatutory regardless of any post-solution activity which makes it available for use by a person or machine for other purposes, In re Walter, 205 USPQ 407.

POST-SOLUTION ACTIVITY

J. Insignificant or non-essential post-solution activity by itself is insufficient to constitute a statutory process. The final step of adjusting an alarm limit as set forth in Parker v. Flook, 437 U.S. 584, 198 USPQ 193 (1978), was not sufficient to render the claim statutory.

Many different types of insignificant post-solution activity have been dealt with by the courts, including

a) the display of the analog equivalent of a number (a shade of gray), In re Walter, 205 USPQ 397, 409 (CCPA 1980);

b) the transmission of data, In re de Castelet, 195 USPQ 439, 446 (CCPA 1977); and

c) the updating of an alarm limit, Parker v. Flook.

The comparing of the integrated polar backscatter with a reference value is of this type and are therefor constitute insignificant post-solution activity. The signal is not claimed to be applied to a physical device to control the device nor is the signal used to "refine or limit" process steps from some overall claimed process. "That the computer is instructed to transmit electrical signals, representing the results of its calculations, does not constitute the type of "post solution activity" found in Flook, supra, and does not transform the claim into one for a process merely <using an algorithm. The final transmitting step constitutes nothing more than reading out the result of the calculations." See In re de Castelet, 195 USPQ 439, 446 (CCPA 1977).

It is readily apparent that when Claims 1 to 10 are each taken as a whole, they are directed to the preemption of a mathematical algorithm, and thus are non-statutory.

According to the above analysis, the identified claims are directed to non-statutory subject matter. The allowance of theses mathematical algorithm claims would pre-empt the mathematical ideas behind them. The 101 statue was designed, in part, to prevent just this occurrence. Therefore, all the claims have been rejected under 35 U.S.C. 101, Gottschalk v Benson, 175 USPQ 673 (S. Ct. 1972). It is conceded that one may not patent an idea. But is practical effect that would be the result if the formula...were patented in this case. The mathematical formula involved here has no substantial practical application except in conjunction with a digital computer, which means that if the judgement below is affirmed, the patent would totally preempt the mathematical formula and in practical effect would be a patent of the algorithm itself.

Claim Rejections - 35 USC § 112

3. Claims 1 to 10 are rejected under 35 U.S.C. § 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention.

A. With respect to Claims 2, 3, 9 and 10, "A" should be "The".

B. With respect to Claims 5 to 7, --The-- should be inserted before "Apparatus".

C. With respect to Claim 1:

i. "the polar backscatter", "said scan site", lacks antecedent basis,

ii. "the measured backscatter power spectra", lacks antecedent basis,

iii. it is not clear that "polar backscatter", "scan sites" is the same backscatter previously stated,

iv. "the remaining power spectrum" needs to be defined with greater specificity, the relationship between the "recorded frequency spectrum" and "the power spectrum needs to be defined with greater specificity.

D. With respect to Claim 2:

i. "the frequency power spectrum", "said amplitude", "said frequency axis", "said intersections of a pari of adjacent straight lines" lack antecedent basis,

ii. how "intersections of a pair of adjacent straight lines" can "span" needs to be defined with greater specificity,

iii. what the relationship between "a frequency where said first derivative has a zero value "and ""the frequencies where said first derivative has zero values" needs to be defined with greater specificity.

E. With respect to Claim 4:

i. "means for causing" needs to be defined with greater specificity,

ii. it is not clear the "frequency ranges excluding the identified frequency ranges" is the same frequency ranges previously stated,

iii. "the net total energy" lacks antecedent basis.

F. With respect to Claim 7:

i. it is not clear that "the means for detecting peaks", "means for identifying frequency ranges", "means for summing", "means for integrating", "means for calculating" and "means for comparing" are the same means previously stated,

ii. "the net total energy" lacks antecedent basis.

G. With respect to <u>Claim 8</u>:

i. "the polar backscatter power", "the composite spectrum", and "the remaining frequency spectrum" lack antecedent basis,

ii. "the remaining frequency spectrum" needs to be defined with greater specificity,

iii. there is no positive recitation of how "a value of the integrated polar backscatter" is related to the previous steps,

iv. what the integrated backscatter is must be defined with greater specificity.

H. With respect to <u>Claim 9</u>:

i. the relationship between "frequency" and "the frequencies" must be defined with greater specificity,

ii. "how the frequency(ies) is related to the frequency spectrum must be defined with greater specificity,

iii. "the zero value" lacks antecedent basis,

iv. "the composite power spectrum" lacks antecedent basis,

v. it is not clear that "peaks and valleys" refer to the same "peaks and valleys" previously stated,

vi. "the composite power spectrum", "the frequency range", "the first derivative plot" lack antecedent basis,

vii. "it is not clear what the relationship between "a frequency" and the frequency(ies) previously stated is,

viii the relationship between "the first derivative having zero values" and the first derivative has a zero value" must be defined with greater specificity.

I. With respect to Claim 10:

i. "the composite power spectrum" and " the total maximum and the total minimum" lack antecedent basis,

ii. the relationship between "differences between peaks and minima" and "difference between peak and minimum" must be defined with greater specificity,

iii. it is not clear that "a quotient" is the same quotient previously stated.

PRIOR ART CITED

The prior art made of record and not relied upon is considered pertinent to applicant's disclosure. References cited but not applied against the claims are considered to be of interest and should be carefully considered by the applicant.

Green teaches an ultrasonic imaging method utilizing integration of a backscatter zone, and combining image and compensation pixel signals to provide for a compensated image pixel signal.

CONTACT INFORMATION

Any inquiry concerning this communication or earlier communications from the examiner should be directed to Christine K. Oda whose telephone number is (703) 305-4896.

Any inquiry of a general nature or relating to the status of this application should be directed to the Group receptionist whose telephone number is (703) 305-4900.

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Christine K. Oda: cko
December 13, 1993

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GROUP 260

NASA Case No. LAR 14535-1 PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of :

Eric I. Madaras :

Serial No.: 08/110,278 : Examiner: C. Oda

Filed: July 16, 1993 : Art Unit: 2605

For: METHOD AND APPARATUS FOR NON-DESTRUCTIVE EVALUATION OF COMPOSITE MATERIALS WITH CLOTH SURFACE IMPRESSIONS

CERTIFICATE OF MAILING

I hereby certify that this correspondence is being deposited with the United States Postal Service by First Class Mail in an envelope addressed to the Commissioner of Patents and Trademarks, Washington, DC 20231 on June 21, 1994.

Date: 6/21/94

LINDA B. B. BLACKBURN

AMENDMENT

Commissioner of Patents and Trademarks
Washington, DC 20231

Sir:

In response to the Office Action mailed December 21, 1993, please amend the above identified patent application as follows:

IN THE SPECIFICATION

Please amend the specification as follows:

On page 2, line 14, please insert --regular-- before the words "surface texture".

On page 3, line 20, please insert --regular-- before the words "surface impressions".

On page 4, line 12, please insert ---regular--- before the words "cloth surface".

On page 4, after line 23 please add the following:

--The theoretical basis for this invention is as follows. In polar backscatter, the sound insonifies the surface at an angle θ with respect to the surface normal. On a composite surface which has a fabric impression, the surface profile will modulate the angle θ so that specific locations are nearly perpendicular to the direction of the insonification and reflect the sound back onto the transducer. To model the surface, consider the surface impressions on a panel formed by a fabric in which fill fibers run horizontally and warp fibers run vertically. This pattern indicates a regularly repeated sequence which can be modeled as a series of planar reflectors. This pattern represents a one dimensional reflection grating that will produce interference effects at the measuring transducer. In order to predict the interference effects, the phase relationship of the system of reflectors must be generated. The following equation for the power is derived:

$$|E(f)|^2=|E_o(f)|^2 M^2 \chi(R,A,a,b)\left(\frac{\sin([N+1]\xi)}{\sin(\xi)}\right)^2\left(\frac{\sin(4\eta)}{\sin(\eta)}\right)^2\left(\frac{\sin(2\gamma)}{\sin(\gamma)}\right)^2.$$

eqn.1

In this equation $|E(f)|^2$ is the reflected signal power, **f** is the frequency, and $E_0(f)$ is the incident signal amplitude. $\chi(R,A,a,b)$ is a function that depends on the reflection coefficient R, the total area insonified, A, the reflector width, a, in the x direction and the reflector width, b, in the y direction. M is the number of repeated patterns in the y direction within the beam. N is the number of repeated patterns in the x direction within the beam. ξ,η,γ are phase terms.

Eq. 1, in general, will produce narrow peaks in its spectrum that represent the effects of the surface impressions.--

On page 9, please delete lines 4-11.

On page 9, lines 16-17, please delete "the theoretical analysis described in the paper referenced above" and add --a theoretical analysis-- in lieu thereof.

IN THE CLAIMS

Please delete claims 1, 4 and 8-10.

Please add claims 11 and 12 in lieu of deleted claims 1 and 4 as follows:

11. A method for non-destructive evaluation of composite materials with regular surface impressions, comprising the steps of:

(a) insonifying at least one scan site on a composite material with ultrasound at a fixed polar angle larger than zero and a fixed azimuthal angle;

(b) detecting a backscattered ultrasound return signal from the composite material;

(c) amplifying the return signal;

(d) transforming the amplified return signal into a polar backscatter power spectrum for each scan site;

(e) summing the polar backscatter power spectra from each scan site to form a composite power spectrum for polar backscatter;

(f) identifying frequency ranges in said composite power spectrum where significant peaks occur;

(g) eliminating said identified frequency ranges from each polar backscatter power spectrum for each scan site of the composite material giving a corrected polar backscatter power spectrum for each scan site;

(h) integrating the corrected polar backscatter power spectrum for each scan site to obtain a value for Integrated Polar Backscatter for each scan site substantially free from artifacts caused by regular impressions on the surface of the composite material; and

(i) displaying a map comprised of pixels, wherein each pixel indicates the value of the substantially artifact-free Integrated Polar Backscatter at a corresponding scan site.

12. An apparatus for non-destructive evaluation of the interior of composite materials having regular surface impressions, comprising:

(a) a broadband ultrasonic transducer in pulse echo mode focused at a test site on the surface of a composite material at a non-normal angle of incidence, and means for causing a wave front to be emitted from said transducer;

(b) amplifying means for amplifying time domain signals from said transducer during predetermined gating intervals;

(c) converting means for converting the amplified time domain signals to a power spectrum in the frequency domain;

(d) a processing means for manipulating the power spectrum, the processing means being capable of detecting peaks in the power spectrum, identifying frequency ranges associated with the peaks, summing frequencies excluding the identified frequency ranges to obtain a net sum of frequencies, integrating the power spectrum over frequencies excluding the identified frequency ranges to obtain a net value for total energy, and calculating the quotient of the net value for total energy and the net sum of frequencies to obtain a quantity known as Integrated Polar Backscatter and comparing the Integrated Polar Backscatter with a reference value to determine if the Integrated Polar Backscatter represents a defective composite material.

Please amend claims 2, 3, 5, 6 and 7 as follows:

2. (Amended) The [A] method for non-destructive evaluation of composite materials with regular surface impressions according to claim [1]11, wherein step [(d)] (f) further comprises the [sub-]steps of:

smoothing the composite [frequency] power spectrum;

plotting the first derivative of said smoothed power spectrum with respect to frequency;

determining the frequencies where said first derivative has zero values;

determining the frequencies where said first derivative has peaks and valleys adjacent to said frequencies corresponding to zero values;

determining the amplitude values for said peaks and valleys;

plotting straight lines intersecting said composite power spectrum at each of said frequencies corresponding to peaks and valleys in the first derivative plot and having slopes equal to said amplitudes[s] values of corresponding said peaks and valleys;

determining where said straight lines intersect the frequency axis of said composite spectrum; and

defining a peak area as the frequency range between a pair of said straight lines, said pair being chosen such that between them lies [said intersections of a pair of adjacent straight lines spanning] a frequency range where said first derivative has a zero value.

3. (Amended) The [A] method for non-destructive evaluation of composite materials with regular surface impressions according to claim [1]11, wherein step [(d)] (f) further comprises the [sub-]steps of:

determining the total maximum and the total minimum amplitude in the composite power spectrum, and calculating the difference therebetween;

determining the differences between peaks and minima for individual peaks in the composite power spectrum;

dividing the difference between peak and minimum for each individual peak by the difference between the total maximum and total minimum and recording the quotient for each division; and

designating as significant those peaks having [a] said quotient exceeding a predetermined threshold value.

5. (Amended) The [A]apparatus for non-destructive evaluation of the interior of composite materials with regular surface impressions according to claim [4]12, wherein said converting means is an analog spectrum analyzer.

6. (Amended) The [A]apparatus for non-destructive evaluation of the interior of composite materials with regular surface impressions according to claim [4]12, wherein said converting means is a digital computer programmed to perform Fourier transforms.

7. (Amended) The [A]apparatus for non-destructive evaluation of the interior of composite materials with regular surface impressions according to claim [4]12, wherein a digital computer is programmed to serve as the processing means. [(d) means for detecting peaks in the power spectrum, (e) means for identifying frequency ranges associated with the peaks, (f) means for summing frequencies excluding the identified frequency ranges to obtain a net sum of frequencies, (g) means for integrating the power spectrum over frequency ranges excluding the identified frequency ranges to obtain a net value for total energy, (h) means for calculating the quotient of the net total energy and the net sum of frequencies to obtain a quantity known as Integrated Polar Backscatter, and (i) means for comparing the integrated Polar Backscatter with a reference value to determine if the Integrated Polar Backscatter represents a defective composite material.]

REMARKS

By Office Action, the drawings are objected to under 37 CFR 1.84. Applicant respectfully requests that drawing corrections be held in abeyance until the application is allowed. The Examiner also stated the attempt to incorporate by reference was improper. Claims 1-10 were rejected under 35 U.S.C. § 101 as being directed to non-statutory subject matter as set forth in the two-step Freeman test. Claims 1-10 were rejected under 35 U.S.C. § 112, second paragraph.

The specification and claims 2,3 and 5-7 have been amended in response to the Examiner's comments and claims 8-10 have been cancelled, claim 1 has been recast as claim 11 and claim 4 has been recast as claim 12. The amended specification and claims contain no new matter within the meaning of 37 C.F.R. 1.118.

The Examiner states that Applicant has improperly attempted to incorporate "essential material" by reference to the paper "Measured Effects of Surface Cloth Impressions on Polar Backscatter and Comparison with a Reflection Grating Model". This reference has been deleted and a portion of the material which was important to the understanding of the invention and has been added in amendment. The amendatory material consists of the same material incorporated by reference on page 2 of the referencing application. Portions of the text have been adapted to clarify the discussion of theory, but the substance of the amendatory material was not changed. A declaration that the amendatory material consists of the same material incorporated by reference is attached.

The claims have been amended in the preambles to more clearly indicate that the invention pertains to the removal of artifacts resulting from regular surface impressions. The specification has also been amended to more clearly indicate that the invention pertains to the removal of artifacts resulting from regular surface impressions. Support for these amendments is found in FIG. 1(a) and in the specification at page 2, lines 15-17, page 3, lines 8-12 and page 8, lines 28-29.

The Examiner has rejected claims 1-10 as directed to non-statutory subject matter under 35 U.S.C. 101. Using the two-step Freeman test, the Examiner has concluded that claims 1-10 "are directed to the preemption of a mathematical algorithm, and are thus non-statutory". In reaching this conclusion, the Examiner has treated apparatus claims 4-7 as method claims because they are written in means-plus-function format. Applicant respectfully submits that recent guidelines published in the Official Gazette of the USPTO on May 17, 1994, require a different interpretation of the "means-or-step-plus-function" limitation than that reached by the Examiner. 1162 OG 59. Under the new guidelines, it is no longer appropriate to interpret a means-plus-function limitation by giving it the "broadest reasonable interpretation". Instead, the issued guidelines explicitly state that "examiners shall interpret a 112, 6th paragraph "means or step plus function" limitation in a claim as limited to the corresponding structure, materials or acts described in the specification and equivalents thereof..." The guidelines further state that "The "means or step plus function" limitation should be interpreted in a manner consistent with the specification disclosure. If the specification defines what is meant by the limitation for the purposes of the claimed invention, the examiner should interpret the limitation as having that meaning." With these recent guidelines in mind, Applicant respectfully points out that each "means" in apparatus claims 4-7 is supported by at least one corresponding structure in the specification. For example, the "amplifying means" of claim 4 is illustrated by an "amplifier" at page 6, lines 23-28. The "converting means" is illustrated at page 6, lines 28-30 as an "analog spectrum analyzer". The "processing means" is illustrated on page 7, lines 18-22 as a "computer". Therefore, since Applicant has defined the meaning of each limitation for the purposes of the claimed invention, it is submitted that apparatus claims 4-7 should not be treated as method claims.

In applying the two-step Freeman test, the Examiner concludes "It is readily apparent that when claims 1-10 are each taken as a whole, they are directed to the preemption of a mathematical algorithm, and thus are non-statutory." Applicant respectfully disagrees with this characterization.

Although claims 1-10 may indirectly recite a mathematical algorithm according to the first step of the Freeman test, the second step of the Freeman test has not been met. That is, the claim in its entirety does not wholly preempt a mathematical algorithm. In applying the second step of the Freeman test, the Examiner asks that the applicant to "...point out the underlying process steps or physical elements to which the mathematical algorithm is applied". In response, Applicant points out that the underlying process in the present invention includes: 1) insonifying a composite specimen to produce backscattered ultrasound that varies according to physical characteristics of the specimen, 2) detection of the backscattered ultrasound, 3) transformation of the detected ultrasound to an electronic signal, 4) display of the electronic signal, and 5) comparison of the electronic signal from the test specimen to electronic signals obtained from similar composite samples containing known defects in order to identify the defects in the test specimen. With regard to the underlying process described above, the court in Abele states: "In any event we view the production, detection and display steps as manifestly statutory subject matter and are not swayed from this conclusion by the presence of an algorithm in the claimed method". 214 USPQ 688. This underlying process has also been found patentable in a number of similar applications that involve production, detection, and display steps. For instance, in the case of Abele which the Examiner cites, the claimed method was directed to the processing of x-ray attenuation signals representative of physical objects. In Arrythmia Research Tech. v. Corazonix Corp., 958 F.2d 1053, the invention concerned signal processing in an electrocardiograph signal that was representative of human cardiograph activity. In In re Johnson, 589 F.2d 1070, the court found that a method for producing seismic waves, receiving a return signal representative of the interior structure of the earth and processing that return signal such that noise was reduced was patentable. In In re Taner, 681 F.2d 787, the signal being processed again was seismic data representative of discontinuities in the earth's structure. The Board in Ex Parte Veldhuis, was more expansive in ruling that an interpolation method for reducing noise in received cellular phone data was statutory.

In the present application, the claims are directed to a physical process and device operating on a composite material which has surface impressions from a release cloth. These surface impressions cause the electronic signal representing the backscattered ultrasound to contain artifacts in the electronic signal. It is the additional step of removing the signal artifacts due to surface impressions on the composite sample that is added to the underlying process detailed above. Since the underlying process and device are themselves statutory, the addition of an algorithm to remove signal artifacts does not render the claims non-statutory. Without the algorithm, the claims would be less useful, but would otherwise still be a statutory process and apparatus for determining physical characteristics of composite specimens. It accordingly is respectfully urged that apparatus claims 4-7 should not be treated as method claims and claims 1-7 are statutory claims under 35 U.S.C. § 101. The same line of argument used for original claims 1 and 4 should hold true for new claims 11 and 12 respectively.

In pursuing the rejection of claims 1-10 based on non-statutory subject matter, the Examiner states that the present claims state "a field of use for the mathematical algorithm which attempts to limit the use of the algorithm to a particular environment". The Examiner also states that "when the mathematical algorithm is merely presented and solved by the claimed invention, field of use limitations are not sufficient to render the claim statutory".

As discussed above, the claims do more than merely present and solve a mathematical algorithm. The algorithm is applied to transform an electrical signal representative of physical features in a composite sample. In addition, the preamble does more than attempt to limit the use of the algorithm to a particular environment. Similar to the Board decision in Veldhuis, in which method and apparatus claims containing limitations in the preamble to the field of signal processing were found patentable under 35 U.S.C. §101, the preamble to the present claims describes something more than a mere field of use. The preamble to the present method and apparatus claims limit the claims and therefore the application of the algorithm to the field of processing ultrasonic signals from composite materials. As stated by the Board, this type of limitation is sufficient to leave other applications of the algorithm in the public domain.

With respect to the Examiner's assertion that the end product of the claimed invention is merely a number, Applicant respectfully disagrees. The product is a corrected integrated polar backscatter which is not a mere number, but rather a transformed, physical, electronic signal containing information about the interior of a composite test specimen.

The Examiner has also indicated that the claims of the present invention contain merely "data gathering" and "insignificant post-solution activity" which are not sufficient to make a non-statutory claim statutory. Applicant respectfully submits that, as discussed above, the underlying process and device are both statutory. Therefore, any additional post-solution steps or data gathering do not render the claims non-statutory.

Claims 1-10 are rejected under 35 U.S.C. 112 as being indefinite. Claim 1 has been restated as claim 11 and modified to provide proper antecedent basis for all terms. Claim 11 has been drafted to clarify the terms and to more clearly show the necessary steps to properly utilize the claimed method. The additional steps are as explained in the specification at pages 6-8. The Examiner's comments on claim 1 have been addressed in the new claim 11.

Claim 2 has been amended to provide proper antecedent basis for all terms and to more clearly show to what frequency ranges are being referred and to more specifically define the relationship between "a frequency" and "the frequencies".

Claim 4 has been restated as claim 12 to more clearly explain the frequency ranges and to provide proper antecedent basis for the terms. In addition, several of the means have been consolidated into a single processing means. With respect to the Examiner's request that "means for causing" be more specifically defined, Applicant points out that one such means, i.e. a pulse generator, is shown at page 6, line 20 by way of example. As discussed above in reference to the new PTO guidelines, "The "means or step plus function" limitation should be interpreted in a manner consistent with the specification disclosure".

Claim 7 has been amended to more clearly show that the means referred to are the same as the means previously stated and to remove the improper reference to "the net total energy".

Claims 8-10 have been cancelled.

Applicant notes the prior art cited by the Examiner, but further comment does not appear necessary at this time

In view of the aforementioned, it is respectfully urged that this application be reconsidered, the claims allowed and this case passed to issue.

Respectfully submitted,

Linda B.B. Blackburn
Reg. No. P-38,385

LBBB/RP

June 21, 1994

804-864-9260

NASA Langley Research Center
Mail Stop 212
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Hampton, VA 23681-0001

US005390544A

United States Patent [19]

[11] Patent Number: 5,390,544

[45] Date of Patent: Feb. 21, 1995

Madras

[54] METHOD AND APPARATUS FOR NON-DESTRUCTIVE EVALUATION OF COMPOSITE MATERIALS WITH CLOTH SURFACE IMPRESSIONS

[75] Inventor: **Eric I. Madras**, Yorktown, Va.

[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration**, Washington, D.C.

[21] Appl. No.: **110,278**

[22] Filed: **Jul. 16, 1993**

[51] Int. Cl.^{6} **G01N 9/24**

[52] U.S. Cl. **73/602**

[58] Field of Search 73/602, 599, 600, 620

[56] References Cited

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Measured Effects of Surface Cloth Impressions on Polar Backscatter and Comparison with a Reflection Grating Model, E. I. Madaras, NASA, Langley Research Center, Hampton, Va. 23665; Edwin F. Brush, III, Dept. of Physics, Colorado College, Colorado Springs, Colo. 80903; S. Lori Bridal, Mark R. Holland, J. G. Miller, Laboratory for Ultrasonics, Dept. of Physics, Washington University, St. Louis, Mo. 63130; 19th Annual Review of Progress in Quantitative Nondestructive Evaluation, La Jolla, Calif., Jul. 20–24, 1992.

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Physical Principles of Ultrasonic Non-Destructive Evaluation of Advanced Composites, Semi-annual Progress Report, Mar. 15–Sep. 14, 1988, Dr. James G. Miller, Principal Investigator, Professor of Physics, Washington University, Dept. of Physics, Laboratory for Ultrasonics, St. Louis, Mo. 63130.

Characterization of Porosity in Graphite/Epoxy Composite Laminates With Polar Backscatter and Frequency Dependent Attenuation, IEEE 1987, Ultrasonics Symposium, pp. 827–830, S. M. Handley, M. S. Hughes, J. G. Miller, Physics Dept., Washington University, St. Louis, Mo. 63130, E. I. Madaras, NASA Langley Research Center, Hampton, Va. 23665.

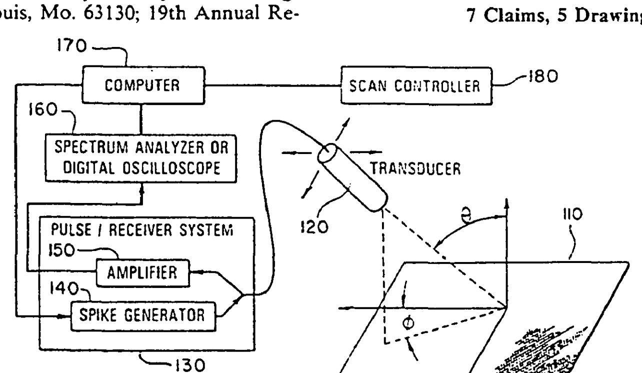
(List continued on next page.)

Primary Examiner—Hezron E. Williams
Assistant Examiner—Christine K. Oda
Attorney, Agent, or Firm—Linda B. B. Blackburn

[57] ABSTRACT

A method and related apparatus for non-destructive evaluation of composite materials by determination of the quantity known as Integrated Polar Backscatter, which avoids errors caused by surface texture left by cloth impressions by identifying frequency ranges associated with peaks in a power spectrum for the backscattered signal, and removing such frequency ranges from the calculation of Integrated Polar Backscatter for all scan sites on the composite material.

7 Claims, 5 Drawing Sheets



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Variations in Ultrasonic Backscatter Attributed to Porosity, Review in Progress in Quantitative NDE v. SB, pp. 1275-1284, D. E. Yuhas, C. L. Vorres, and Ron Roberts, Magnaflux Advanced Research, 2301 Arthur Avenue, Elk Grove Village, Ill. 60007.

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Porosity Characterization in Fiber-Reinforced Composites By Use of Ultrasonic Backscatter, Review in Progress in Quantitative NDE v. GB, pp. 1147-1156, (1987), Ronald A. Roberts, Materials and Components Technology Division, Argonne National Laboratory, Argonne, Ill. 60439.

An Investigation of the Relationship Between Contrast and Azimuthal Angle for Imaging Porosity in Graphite/Epoxy Composites with Ultrasonic Polar Backscatter, 1988 IEEE Ultrasonic Symposium, Chicago, Ill., Oct. 2-5, 1988, S. M. Handley, J. G. Miller, Dept. of Physics, Washington University, St. Louis, Mo. 63130; Eric Madaras, NASA Langley Research Center, M/S 231, Hampton, Va. 23665, 1988.

FIG. 1(a)

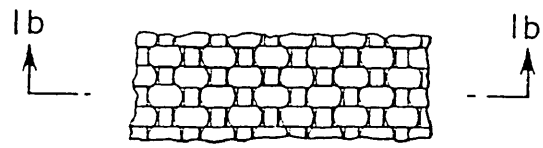


FIG. 1 (b)

FIG. 2

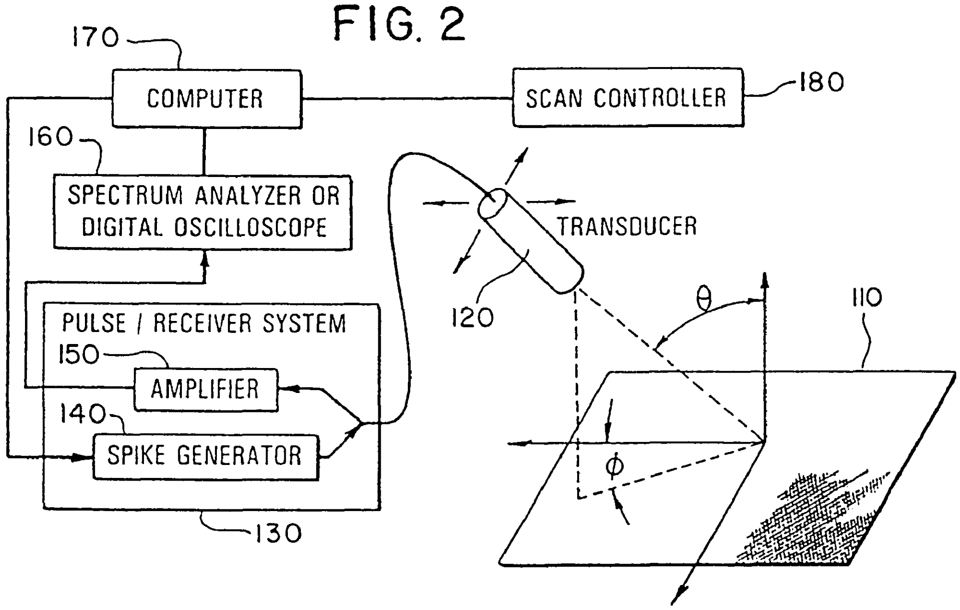


FIG. 4(a)

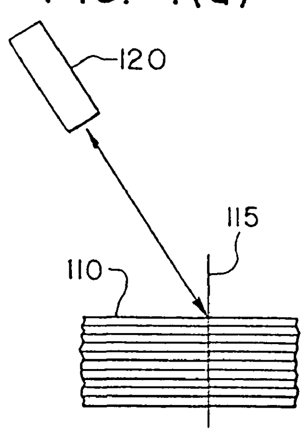


FIG. 4(b)

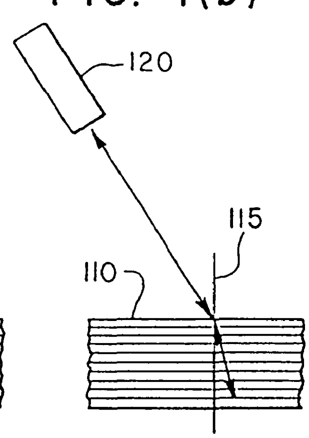


FIG. 4(c)

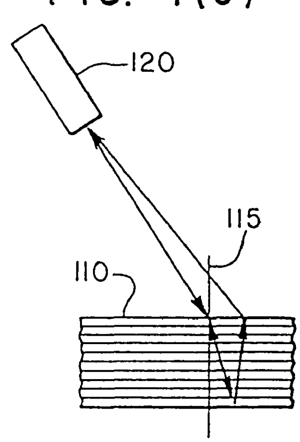


FIG. 3(a)

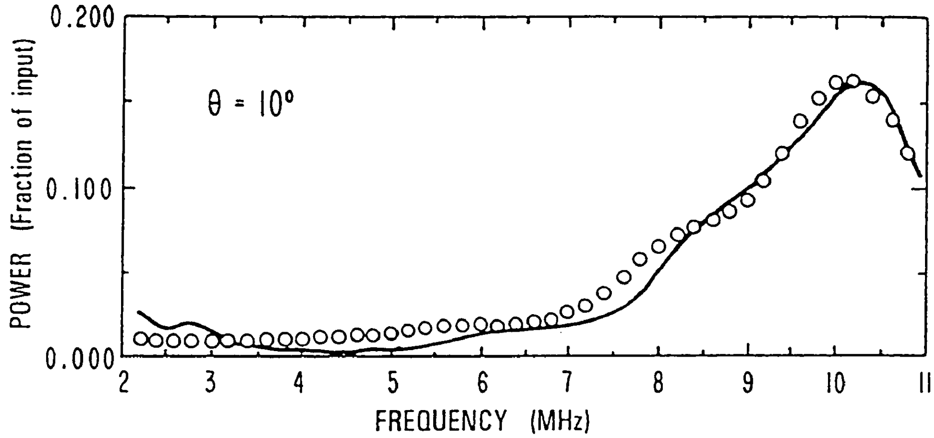


FIG. 3(b)

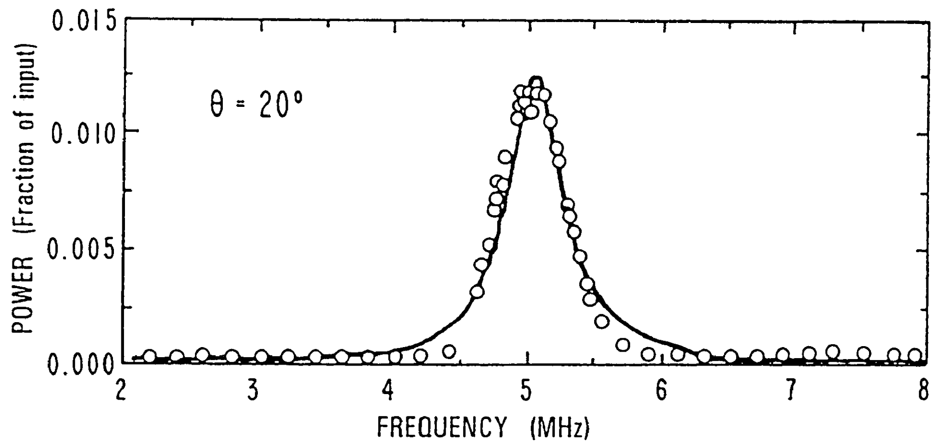


FIG. 3(c)

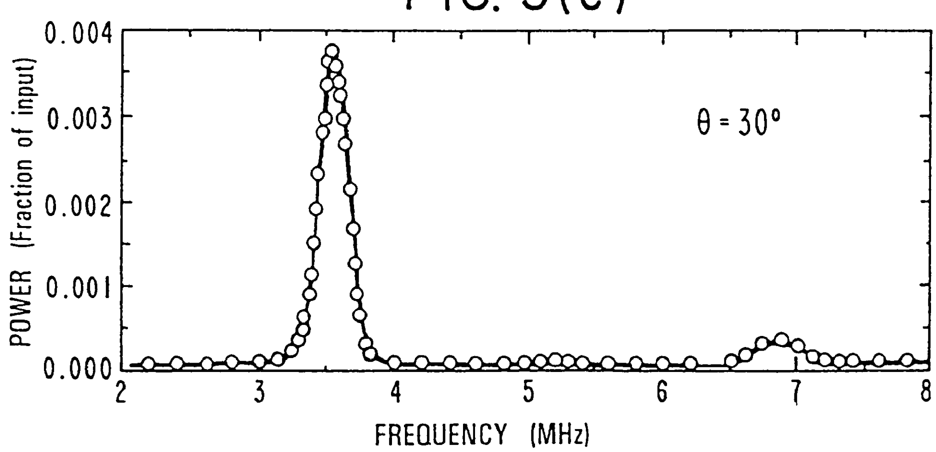


FIG. 5

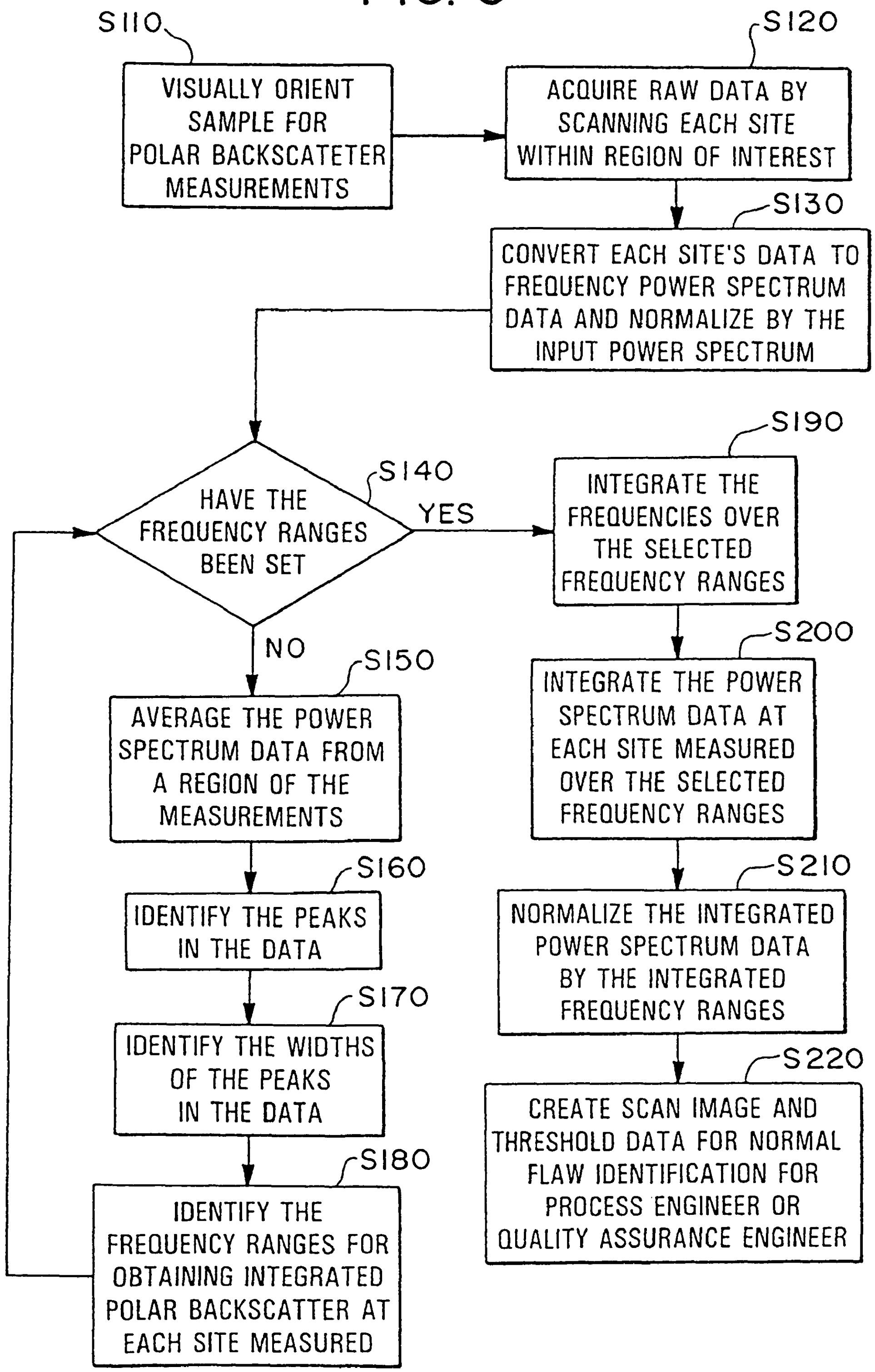

S110
VISUALLY ORIENT SAMPLE FOR POLAR BACKSCATETER MEASUREMENTS
S120
ACQUIRE RAW DATA BY SCANNING EACH SITE WITHIN REGION OF INTEREST
S130
CONVERT EACH SITE'S DATA TO FREQUENCY POWER SPECTRUM DATA AND NORMALIZE BY THE INPUT POWER SPECTRUM
S140
HAVE THE FREQUENCY RANGES BEEN SET
YES
NO
S150
AVERAGE THE POWER SPECTRUM DATA FROM A REGION OF THE MEASUREMENTS
S160
IDENTIFY THE PEAKS IN THE DATA
S170
IDENTIFY THE WIDTHS OF THE PEAKS IN THE DATA
S180
IDENTIFY THE FREQUENCY RANGES FOR OBTAINING INTEGRATED POLAR BACKSCATTER AT EACH SITE MEASURED
S190
INTEGRATE THE FREQUENCIES OVER THE SELECTED FREQUENCY RANGES
S200
INTEGRATE THE POWER SPECTRUM DATA AT EACH SITE MEASURED OVER THE SELECTED FREQUENCY RANGES
S210
NORMALIZE THE INTEGRATED POWER SPECTRUM DATA BY THE INTEGRATED FREQUENCY RANGES
S220
CREATE SCAN IMAGE AND THRESHOLD DATA FOR NORMAL FLAW IDENTIFICATION FOR PROCESS ENGINEER OR QUALITY ASSURANCE ENGINEER

FIG. 6(a)

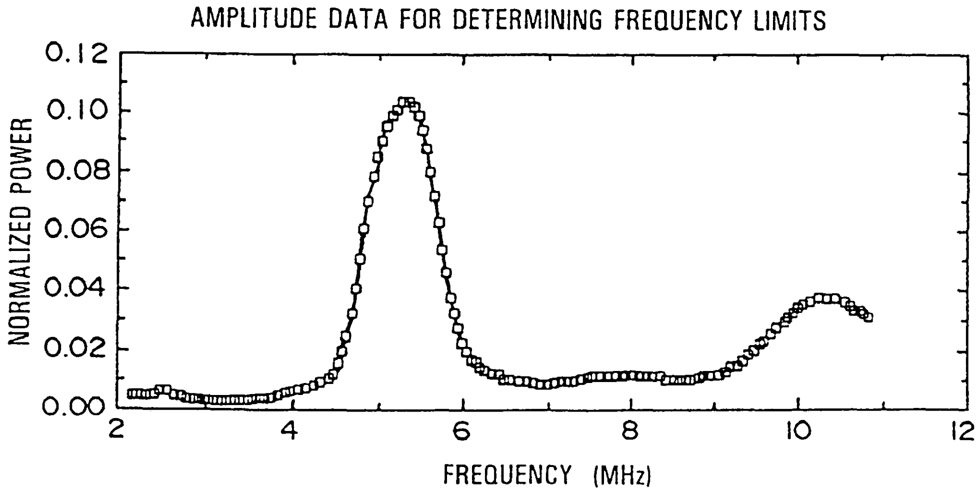

AMPLITUDE DATA FOR DETERMINING FREQUENCY LIMITS
NORMALIZED POWER
0.12
0.10
0.08
0.06
0.04
0.02
0.00
2
4
6
8
10
12
FREQUENCY (MHz)

FIG. 6(b)

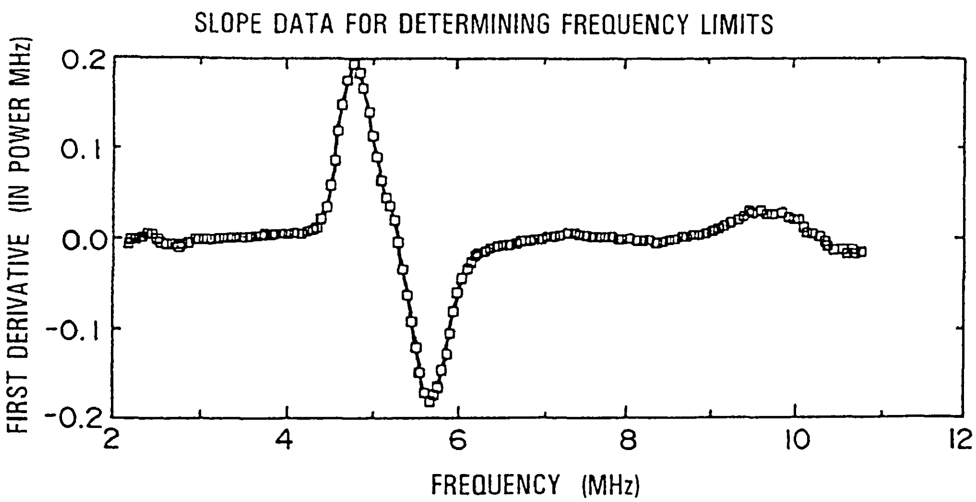

SLOPE DATA FOR DETERMINING FREQUENCY LIMITS
FIRST DERIVATIVE (IN POWER MHz)
0.2
0.1
0.0
-0.1
-0.2
2
4
6
8
10
12
FREQUENCY (MHz)

FIG. 6(c)

PROCESSING STEPS FOR FINDING FREQUENCY LIMITS

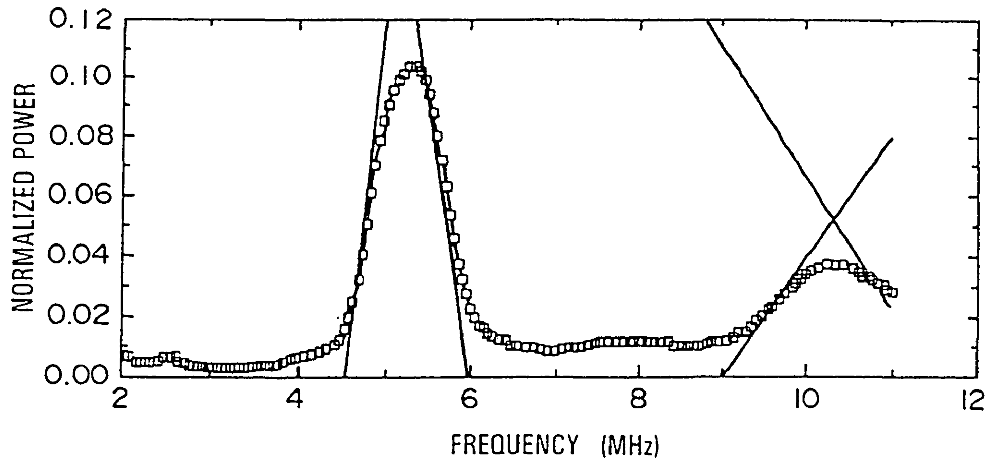
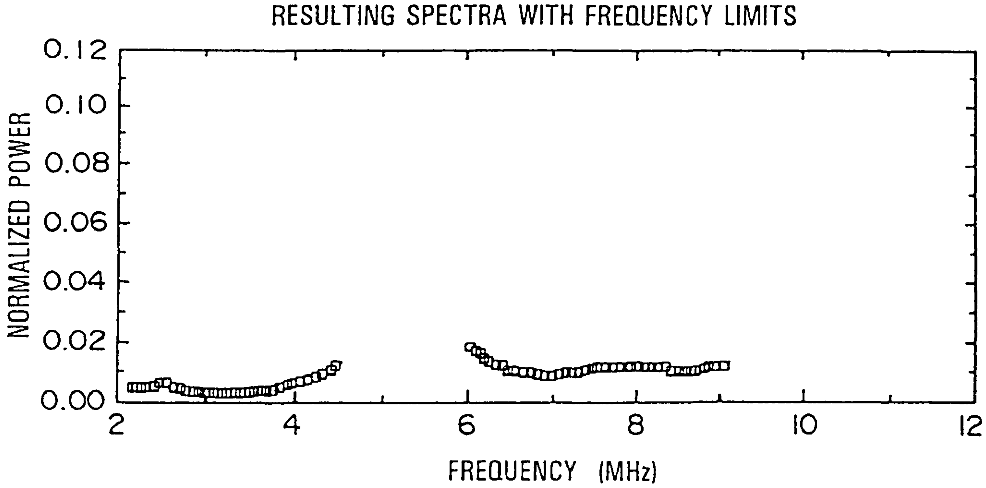


FIG. 6(d)

RESULTING SPECTRA WITH FREQUENCY LIMITS



METHOD AND APPARATUS FOR NON-DESTRUCTIVE EVALUATION OF COMPOSITE MATERIALS WITH CLOTH SURFACE IMPRESSIONS

Origin of the Invention

The invention described herein was made by an employee of the U.S. Government and may be manufactured and used by or for the government for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to non-destructive evaluation of materials by ultrasonic methods, and specifically to the quantitative evaluation of the internal condition of composites by the measurement of Integrated Polar Backscatter from a composite material insonified by an ultrasonic transducer at a non-normal angle of incidence.

2. Description of the Related Art

In a known method for quantitative evaluation of the internal condition of a composite material, the composite is insonified by a single ultrasonic transducer at a non-normal angle of incidence, and a quantity called the Integrated Polar Backscatter is used as a measure of the condition of the composite. The Integrated Polar Backscatter is defined as the total energy of the backscatter signal detected by the transducer over preset frequency ranges, divided by the sum of the frequencies in the preset frequency ranges. The backscatter signals are usually normalized by comparison with the backscatter signal obtained from a reference object, such as a polished stainless steel plate in the same test setup.

When the composite material being tested has a smooth surface, the non-normal angle of incidence of the ultrasonic signal causes the reflected portion of the incident signal to be directed away from the transducer, so it does not contribute to the detected signal. The rest of the incident signal is refracted into the composite, where matrix cracking, porosity, inclusions, or other defects will cause a backscatter signal to be returned to the transducer. Integrated Polar Backscatter accordingly provides an accurate measure of the condition of a composite that has a smooth surface.

In practice, the surface of a composite material is not totally smooth, but has a regular surface texture caused by impressions from a "release cloth", which is a fine mesh cloth impregnated with teflon, used to keep the composite from sticking to the surfaces of the curing press. Such a surface texture causes some of the reflected ultrasonic signal to be directed back to the ultrasonic transducer, so the Integrated Polar Backscatter will have a constant component, independent of the condition of the interior of the composite. This surface backscatter obscures variations in the Integrated Polar Backscatter caused by internal defects, and can make the Integrated Polar Backscatter useless as a quality measure, unless precautions are taken to alleviate the effect of the surface texture.

The obvious remedy for a surface texture is to remove it. Grinding is not a useful method, but a strippable coating of a material with ultrasonic properties matching those of the composite can be applied to the surface of the composite to smooth out the surface texture and effectively eliminate the detrimental effect of

the cloth impressions. The application of a coating before the ultrasonic evaluation, and stripping it off afterwards, are time consuming and expensive processes, however. Sometimes quality approval of both the coating material and the application and stripping processes would also be required, which effectively could rule this method out.

An alternate method for reducing the backscattering effect of the cloth impressions involves careful azimuthal alignment of the transducer and the composite material until minimal surface backscatter is obtained. A minimum in the surface backscatter is obtained when the incident signal is parallel to the impressions from either the weft threads or the warp threads in the release cloth. Generally, the surface backscatter has an absolute minimum when the incident signal is in-between the weft threads and warp threads directions. This alignment method can reduce the effect of surface backscatter to tolerable levels in most cases, but the azimuthal alignment is a cumbersome process that is difficult to automate.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a new method and apparatus for accurate ultrasonic evaluation of the internal condition of a composite material having regular surface impressions from a release cloth through the measurement of Integrated Polar Backscatter.

Another object of the present invention is to provide a method for correctly computing the quantity known as Integrated Polar Backscatter when applied to composite materials with cloth surface impressions.

It is still another object of the present invention to provide a method and apparatus for evaluating the interior of a composite material through the measurement of Integrated Polar Backscatter that can identify and remove signal components caused by surface texture on the composite material.

Even another object of the present invention is to provide a method and apparatus for ultrasonic evaluation of the interior of a composite material by polar backscatter, including elimination of data collected over particular frequency ranges associated with surface texture,

It is a still further object of the present invention to provide a new method for evaluation of the interior condition of a composite material by measurement of the quantity known as Integrated Polar Backscatter, which involves automatic detection of effects from surface texture and automatic elimination of such effects from the measured quantity.

In order to achieve the foregoing and other objects, in accordance with the purposes of the present invention as described herein, a method for non-destructive evaluation of composite materials with regular cloth surface impressions comprises the steps of insonifying a series of scan sites on the composite material sequentially with ultrasound at a fixed polar angle larger than zero, recording a power spectrum of the polar backscatter for each scan site, adding the measured backscatter power spectra from several of said scan sites to form a composite power spectrum for polar backscatter, identifying frequency ranges in the composite power spectrum where peaks occur, eliminating the identified frequency ranges from each power spectrum for scan sites of the composite material, and integrating the remaining power spectrum for each scan site to obtain a value for Integrated Polar Backscatter for each scan site substantially free from errors caused by cloth impressions on the surface of the composite.

The theoretical basis for this invention is as follows. In polar backscatter, the sound insonifies the surface at an angle Θ with respect to the surface normal. On a composite surface which has a fabric impression, the surface profile will modulate the angle Θ so that specific locations are nearly perpendicular to the direction of the insonification and reflect the sound back onto the transducer. To model the surface, consider the surface impressions on a panel formed by a fabric in which fill fibers run horizontally and warp fibers run vertically. This pattern indicates a regularly repeated sequence which can be modeled as a series of planar reflectors. This pattern represents a one dimensional reflection grating that will produce interference effects at the measuring transducer. In order to predict the interference effects, the phase relationship of the system of reflectors must be generated. The following equation for the power is derived:

$$|E(f)|^2 = |E_0(f)|^2 M\chi(R,A,a,b)\left(\frac{\sin([N+1]\xi)}{\sin(\xi)}\right)^2\left(\frac{\sin(4\eta)}{\sin(\eta)}\right)^2\left(\frac{\sin(2\gamma)}{\sin(\gamma)}\right)^2. \quad \text{eqn. 1}$$

In this equation $|E(f)|^2$ is the reflected signal power, f is the frequency, and $E_0(f)$ is the incident signal amplitude. X(R,A,a.b) is a function that depends on the reflection coefficient R, the total area insonified, A, the reflector width, a, in the x direction and the reflector width, b, in the y direction. M is the number of repeated patterns in the y direction within the beam. N is the number of repeated patterns in the x direction within the beam. ξ,η,Y are phase terms.

Eq. 1, in general, will produce narrow peaks in its spectrum that represent the effects of the surface impressions.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings illustrate several aspects of the present invention and, together with the descriptions, serve to explain the principles of the invention.

FIGS. 1(*a*) and 1(*b*) are an enlarged top view and enlarged sectional view, respectively, showing the surface of a composite material with release cloth imprint;

FIG. 2 is a partly schematic illustration of an apparatus for performing the present invention;

FIGS. 3(*a*), 3(*b*) and 3(*c*) are graphs illustrating frequency spectra for reflected energy at various polar angles Θ;

FIGS. 4(*a*), 4(*b*) and 4(*c*) are schematic views illustrating different origins of backscatter signals returned from a composite material;

FIG. 5 is a flow chart for a method of computing Integrated Polar Backscatter with surface effects eliminated; and

FIGS. 6(*a*), 6(*b*), 6(*c*) and 6(*d*) are graphs illustrating different steps in the method for eliminating frequency ranges containing the surface backscatter signal.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1(*a*) is an enlarged top view of a composite material, such as a sheet of epoxy/graphite laminate, with a typical surface texture. FIG. 1(*b*) is an enlarged sectional view taken along line 1*b*—1*b* in FIG. 1(*a*) through the surface of the same material. The depressions visible in FIG. 1(*b*) are caused by a release cloth used during manufacture to prevent the laminate from sticking to the surfaces of a curing press. The release cloth is stripped off the laminate after the curing is completed.

FIG. 2 is a partly schematic illustration of an apparatus for ultrasonic evaluation of a composite material **110** by measurement of Integrated Polar Backscatter according to the present invention. An ultrasonic transducer **120** is aimed at a composite material **110** at a predetermined polar angle Θ and a predetermined azimuthal angle φ. The transducer **120** is typically a broadband transducer with 5 MHz center frequency, 4 inch focal distance, and 0.5 inch focus width, and it is used in a pulse echo mode. Both the transducer **120** and the composite material **110** are immersed in water or some other suitable coupling medium during measurements.

In order to scan a selected area of the composite sample material **110**, the transducer **120** is arranged movable relative to the composite sample material **110** while the polar angle Θ and the azimuthal angle φ are kept constant. After a measurement has been made at one scan site, the relative position is changed by a small increment, e.g. 1/16 inch, and a new measurement is made at the new scan site. This process is repeated until all desired scan sites have been measured. The area insonified by the transducer **120** is typically about ½ inch wide, which is larger than the distance between successive scan sites, so successive scans overlap.

A pulser/receiver system **130** contains a spike generator **140**, which periodically generates a spike of approximately −150V to approximately −300V, causing the transducer **120** to emit an ultrasonic wave front aimed at the composite material **110**. The pulser/receiver system **130** also contains an amplifier **150** for amplifying backscattered RF signals received by the transducer **120**, and a 5μs stepless gate (not shown), which is set to open just before the first reflection is received by the transducer 120. A suitable amplifier **150** is Metrotek MR 106 with a Metrotek MG 701 stepless gate. The output of the amplifier **150** is fed to a spectrum analyzer **160**, e.g. a Hewlett Packard 8557 Analog Spectrum Analyzer, which converts the detected time domain signal into a power spectrum and displays it. The signal from the amplifier **150** can alternatively be fed to a device for performing a Fourier transform of the time domain signal, for instance a digital oscilloscope capable of displaying a Fourier transformed frequency plot. In either case, in FIGS. 3(*a*) through 3(*c*), a power spectrum of the backscatter signal is displayed with frequency along the abscissa, and the square of the signal strength along the ordinate. The energy in any frequency band is then the area under the graph line in the frequency band.

The reflected signal is typically expressed as a ratio of the amplitude output of the amplifier **150** for the measured backscatter from a composite material as compared with the amplitude of the signal output of the amplifier **150** from a standard material in place of the composite material **110**, e.g. a polished metal plate. This normalized signal amplitude is used in all calculations. The normalized amplitude spectrum and power spectrum are commonly displayed on a logarithmic scale and expressed in decibels (dB), but the calculations described below are ordinarily based on linear data values.

The output from the spectrum analyzer or digital oscilloscope 160 is fed to a computer 170, which contains circuitry for controlling the gathering of data, and programs for eliminating signals generated by surface texture on the composite material 110, as will be described in detail below.

FIGS. 4(*a*) through 4(*c*) illustrate three types of backscattered signals, which are detected by the transducer 120 and forwarded to the spectrum analyzer 160. Lines 115 are lines normal to the surface of the composite sample material 110.

FIG. 4(*a*) shows backscatter from the surface of the composite sample material 110. This surface backscatter is negligibly small when the composite sample material 110 has a perfectly smooth top surface, because the signal reflected by the surface in that case will exit to the right of the normal 115 when the polar angle Θ is larger than zero. If, however, the surface of the composite sample material 110 has a surface texture, e.g. impressions from a release cloth as shown in FIGS. 1(*a*) and 1(*b*), the surface texture can cause a significant amount of surface backscatter. This surface backscatter can become so large that it dominates the total backscatter signal. It is the object of the present invention to eliminate its effect on the backscatter measurement.

FIG. 4(*b*) shows backscatter signal from the interior of the composite sample material 110 by an incident signal refracted into the sample material 110. A flawless composite material will produce a small amount of backscatter of this mode, caused by different sound velocities in the matrix material and the reinforcing fibers of the composite sample material 110. A composite material suffering from delaminations or other defects in the interior of the sample 110 will, however, produce a much larger backscatter signal, and it is this mode of backscatter signal that is desirable for evaluation of the quality of the composite sample material 110.

FIG. 4(*c*) shows backscatter signal from the far side of the composite sample material 110. This mode of backscatter causes only a small, substantially constant backscatter signal, which does not seriously affect the desired backscatter signal from the mode illustrated in FIG. 4(*b*).

The test apparatus shown in FIG. 2 has a transducer 120 that emits an ultrasonic beam with a transducer width of ½-inch, so a large number of the small depressions on the surface of the composite material 110 are insonified simultaneously, and the distance between adjacent peaks in the surface texture is comparable to the wavelength of the ultrasonic wave in the coupling medium (water), which is about 0.03 mm at the center frequency of the transducer 120. Under these circumstances, the surface texture on the composite material 110 acts as an ultrasonic grate, so ultrasonic waves will be deflected at different angles to the normal 115 depending on their frequencies. This means that the surface backscatter signal returned to the transducer 120 will contain one or more narrow frequency bands generated by this grating effect.

FIGS. 3(*a*) through 3(*c*) are graphs showing the power spectra obtained with the apparatus shown in FIG. 2, using samples of laminate with surface texture as illustrated in FIG. 1(*b*), for different polar angles Θ. The dots represent measured data, while the full solid lines represent data obtained from a theoretical analysis. The agreement between theory and measurement is good. The way the frequencies where peaks appear in FIGS. 3(*a*) through 3(*c*) change with the polar angle Θ is in itself clear indication that the peaks are caused by the grating effect of the surface texture on the composite sample material 110.

The total energy in a frequency range is defined as the area under a power spectrum between the ends of the frequency range. It is evident from FIGS. 3(*a*) through 3(*c*) that the areas under the peaks are the major part of the total area under the power spectrum. These parts of the total energy are, however, caused by the surface texture of the composite material, as explained above, so they are independent of the interior quality of the composite material. Accordingly, a much improved measure of the interior quality of a composite material will be obtained if those frequency ranges where peaks occur in the power spectrum are excluded from the calculation of Integrated Polar Backscatter.

The frequency ranges to be excluded according to the present invention are those that exhibit significant peaks caused by the grating effect of the surface texture. These excluded frequency ranges can easily be determined for a particular composite material at a particular polar angle Θ and azimuthal angle φ, either manually or by a computer algorithm, as will be described below. Correct values for Integrated Polar Backscatter, independent of artifacts caused by surface texture, can then be obtained for later scan sites on the composite material 110 by integrating the power only over the frequency ranges not excluded.

FIG. 5 is a flow chart of a method for computer processing of the data received from the transducer 120 via the spectrum analyzer 160.

In step S 110, the azimuthal angle φ of the composite sample material 110 is visually oriented relative to the transducer 120. The composite sample material 110 should in step S110 preferably be aligned so azimuth φ=0 corresponds to the direction of impressions from weft threads in the surface of the composite material 110; but exact alignment of the sample material is not necessary, as long as the azimuthal angle φ remains constant during the entire test sequence.

In step S120, the surface of the composite sample material 110 is scanned by the transducer 120 over an area of interest to obtain raw data.

In step S130, the raw time domain data from step S120 is next transformed into the frequency domain using a spectrum analyzer or digital Fourier transform methods, and the power spectrum is calculated. This power spectrum is normalized (calibrated) by a reference signal earlier obtained from a polished stainless steel plate used as a target instead of the composite sample material 110 to represent the power that is transmitted into the composite sample material 110. The recording of the raw time domain data and conversion to a power spectrum in the frequency domain can be made by modern digital oscilloscopes, which have internal numerical signal processing computers that are optimized for fast and efficient Fourier transforms and can internally store and subtract signals. A spectrum analyzer could instead be used to give the power spectrum directly. A spectrum analyzer often has very high fidelity, but may be slower. Alternatively, the conversion by digital Fourier transform methods could also be performed within the computer 170.

In step S140, it is determined if the frequency ranges affected by surface backscatter have been set. If they have not been set, which is the case when a new sample 110 is being analyzed, step S140 continues to step S150. If the frequency ranges have been set, step S140 continues to step S190.

In step S150, all of the data, or data from a few selected scan sites, are next averaged to form a composite power spectrum, which will be used to determine which frequency ranges are affected by surface backscatter. Scans over a small region can often be used to identify the frequency ranges of interest for the whole data set.

The processing after step S150 continues in step S160, where significant peaks are identified by using a maximum/minimum identification algorithm. The significant peaks can be selected by first identifying the maximum and minimum power amplitudes in the entire frequency range, and calculating the maximum minus minimum value. Significant individual peaks would then typically be defined as peaks with a peak maximum minus peak minimum value that is greater than 20% of the overall maximum minus minimum value, or in mathematical terms:

(peak max-peak min)/(max-min) > 0.2.

Maximum/minimum identification algorithms could scan the data set in a straight forward manner testing for peaks and minima, or alternatively, by numerically differentiating the power spectrum (in the linear domain) with respect to the frequency, and testing those results for positive to negative transitions, which will identify frequencies where the power spectrum has undergone a maximum. It may be necessary to smooth the data, e.g. by means of a low pass filter, in order to remove signal noise before the differentiation.

FIG. 6(*a*) is a plot of smoothed data from a composite sample material 110 of normalized power plotted with respect to frequency. The surface texture on the composite sample material 110 introduces the signal artifacts appearing as peaks in FIG. 6(*a*). It is easily calculated that a minimum power of 0.00298 occurs at a frequency of 3.1 MHz, and a maximum power of 0.10584 occurs at a major peak at a frequency of 5.4 MHz. The max-min is therefore 0.10286. At a 20% cutoff, there is only one other significant peak, located at a frequency of 10.3 MHz.

FIG. 6(*b*) is a plot of the first derivative of the data of FIG. 6(*a*). The two significant peaks can be identified by their positive to negative transitions points at frequencies 5.4 MHz and 10.3 MHz in the first derivative data.

In step 170 of FIG. 5, the widths of the major peaks are determined. This is easiest to do by testing for maxima and minima in the first derivative with respect to frequency. Such maxima and minima in the first derivative represent the frequency locations of the "half widths" of the peaks. From FIG. 6(*b*), the locations of the maximum and minimum positions identify the steepest slopes as well as the frequencies where they occur. In the case shown in FIG. 6(*b*), the locations are first peak left half width at a frequency of 4.8 MHz, first peak right half width at a frequency of 5.65 MHz, second peak left half width at a frequency of 9.6 MHz and second peak right half width at a frequency of 10.75 MHz.

In step S180 of FIG. 5, the frequency ranges to be used in the calculation of Integrated Polar Backscatter for each scan site are determined. Once the half width locations are found as explained above with reference to step S170, the values for the maxima and minima in the first derivative data give the slopes of the peaks at the half width locations. The straight lines shown in FIG. 6(*c*) are calculated by step S180. They are tangents to the slopes of the peaks at the frequencies calculated under step S170, and their slopes are defined by the values of the maxima and minima in the first derivative with respect to frequency at those frequencies, as illustrated in FIG. 6(*b*). The resulting intercepts with the abscissa are frequencies of 4.6 MHz, 6.05 MHz and 9.05 MHz. Each frequency range between a pair of intersections spanning a peak represents a frequency range tainted by surface backscatter from surface texture, and all such frequency ranges should be eliminated from the calculation of the Integrated Polar Backscatter. Only the remaining frequency ranges are identified in step S180 of FIG. 5, and only these frequency ranges will be used in calculating the Integrated Polar Backscatter for each scan site.

FIG. 6(*d*) is a graph showing a normalized power spectrum for the resulting usable frequency ranges for analyzing the composite sample material 110. The other frequency ranges have been excluded because these were determined by the above procedure as containing erroneous data due to surface texture. Thus, by integration over only the ranges indicated in FIG. 6(*d*), the effect of surface texture is eliminated from the calculated Integrated Polar Backscatter.

After the frequency ranges have been set by steps S150 through S180, step S140 proceeds to the procedure for integration and detection of flaws in steps S190 through S220.

In step S190 of FIG. 5, the usable frequency ranges defined in step S180 are summed, thereby defining the denominator in later calculations of Integrated Polar Backscatter.

In step S200 of FIG. 5, the power spectrum for each scan element previously recorded under step S120, or recorded separately later on, is first derivative data give the slopes of the peaks at the half width locations. The straight lines shown in FIG. 6(*c*) are calculated by step S180. They are tangents to the slopes of the peaks at the frequencies calculated under step S170, and their slopes are defined by the values of the maxima and minima in the first derivative with respect to frequency at those frequencies, as illustrated in FIG. 6(*b*). The resulting intercepts with the abscissa are frequencies of 4.6 MHz, 6.05 MHz and 9.05 MHz. Each frequency range between a pair of intersections spanning a peak represents a frequency range tainted by surface backscatter from surface texture, and all such frequency ranges should be eliminated from the calculation of the Integrated Polar Backscatter. Only the remaining frequency ranges are identified in step S180 of FIG. 5, and only these frequency ranges will be used in calculating the Integrated Polar Backscatter for each scan site.

FIG. 6(*d*) is a graph showing a normalized power spectrum for the resulting usable frequency ranges for analyzing the composite sample material 110. The other frequency ranges have been excluded because these were determined by the above procedure as containing erroneous data due to surface texture. Thus, by integration over only the ranges indicated in FIG. 6(*d*), the effect of surface texture is eliminated from the calculated Integrated Polar Backscatter.

After the frequency ranges have been set by steps S150 through S180, step S140 proceeds to the procedure for integration and detection of flaws in steps S190 through S220.

In step S190 of FIG. 5, the usable frequency ranges defined in step S180 are summed, thereby defining the denominator in later calculations of Integrated Polar Backscatter.

In step S200 of FIG. 5, the power spectrum for each scan element previously recorded under step S130, or recorded separately later on, is integrated over the usable frequency ranges determined in Step S180 to obtain the total energy.

In step S210 of FIG. 5, the total energy for each scan site calculated in step S200 is divided by the summed frequencies calculated in step S190, to produce an Integrated Polar Backscatter value for each scan site by normalization.

Finally, in step S220 of FIG. 5, a visual map is generated, with each scanned site being identified by a small square or rectangle ("pixel"). The color or gray level of the pixel can be used to provide an image representing the amplitude of the integrated polar backscatter. This visual map can also be thresholded to produce a binary image representing good versus flawed material.

The present invention offers several important advantages over the prior art. A major advantage is that it requires no sample preparation for implementation. The present invention further requires only that digital data be obtained for processing in the frequency domain, and this is already becoming the standard method of ultrasonic data acquisition in field installations. The method according to the invention can also be performed using software with the data after the scan has been finished, so it has little impact on the initial data scan time for the sample.

Many variations of the method and apparatus described herein are possible within the scope of the invention. For instance, frequency ranges where the recorded power is tainted by surface backscatter can be determined by fitting measured data to formulas based on grating theory, instead of by the empirical determination described above.

The composite power spectrum used to determine the tainted frequency ranges can be based on data from all the measured scan sites when a complete set of data is recorded, and the Integrated Polar Backscatter can be calculated from the recorded data base. Alternatively, data from only a few selected scan sites can first be used to determine the excluded frequency ranges, and a full set of scans can later be taken, with each pixel immediately being identified as either good or bad as the scan is progressing.

It would also be possible to do the summation for the composite power spectrum in the logarithmic domain, instead of in the linear domain. Because of the signal compression that the logarithmic values represent, this would improve the signal to noise ratio. It would, however, be necessary to convert the composite power data to linear values before further calculations to determine the frequency ranges to be excluded.

Numerous further modifications and adaptations of the present invention will become apparent to those skilled in the art. Thus, the following claims are intended to cover all such modifications and adaptations which fall within the true spirit and scope of the present invention.

What is claimed is:

1. A method for non-destructive evaluation of composite materials with regular surface impressions, comprising the steps of:
   (a) insonifying at least one scan site on a composite material with ultrasound at a fixed polar angle larger than zero and a fixed azimuthal angle;
   (b) detecting a backscattered ultrasound return signal from the composite material;
   (c) amplifying the return signal;
   (d) transforming the amplified return signal into a polar backscatter power spectrum for each scan site;
   (e) summing the polar backscatter power spectra from each scan site to form a composite power spectrum for polar backscatter;
   (f) identifying frequency ranges in said composite power spectrum where significant peaks occur;
   (g) eliminating said identified frequency ranges from each polar backscatter power spectrum for each scan site of the composite material giving a corrected polar backscatter power spectrum for each scan site;
   (h) integrating the corrected polar backscatter power spectrum for each scan site to obtain a value for Integrated Polar Backscatter for each scan site substantially free from artifacts caused by regular impressions on the surface of the composite material; and
   (i) displaying a map comprised of pixels, wherein each pixel indicates the value of the substantially artifact-free Integrated Polar Backscatter at a corresponding scan site.

2. A method for non-destructive evaluation of composite materials with regular surface impressions according to claim 1, wherein step (f) further comprises the steps of:
   smoothing the power spectrum;
   plotting the first derivative of said smoothed power spectrum with respect to frequency;
   determining the frequencies where said first derivative has zero values;
   determining the frequencies where said first derivative has peaks and valleys adjacent to said frequencies corresponding to zero values;
   determining the amplitude values for said peaks and valleys;
   plotting straight lines intersecting said composite power spectrum at each of said frequencies corresponding to peaks and valleys in the first derivative plot and having slopes equal to said amplitudes values of corresponding said peaks and valleys;
   determining where said straight lines intersect the frequency axis of said composite spectrum; and
   defining a peak area as the frequency range between a pair of said straight line said pair being chosen such that between them lies a frequency range where said first derivative has a zero value.

3. The method for non-destructive evaluation of composite materials with regular surface impressions according to claim 1, wherein step (f) further comprises the steps of:
   determining the total maximum and the total minimum amplitude in the composite power spectrum, and calculating the difference therebetween;
   determining the differences between peaks and minima for individual peaks in the composite power spectrum;

dividing the difference between peak and minimum for each individual peak by the difference between the total maximum and total minimum and recording the quotient for each division; and

designating as significant those peaks having said quotient exceeding a predetermined threshold value.

4. An apparatus for non-destructive evaluation of the interior of composite materials having regular surface impressions, comprising:

(a) a broadband ultrasonic transducer in pulse echo mode focused at a test site on the surface of a composite material at a non-normal angle of incidence, and means for causing a wave front to be emitted from said transducer;

(b) amplifying means for amplifying time domain signals from said transducer during predetermined gating intervals;

(c) converting means for converting the amplified time domain signals to a power spectrum in the frequency domain;

(d) a processing means for manipulating the power spectrum, the processing means being capable of detecting peaks in the power spectrum, identifying frequency ranges associated with the peaks, summing frequencies excluding the identified frequency ranges to obtain a net sum of frequencies, integrating the power spectrum over frequencies excluding the identified frequency ranges to obtain a net value for total energy, and calculating the quotient of the net value for total energy and the net sum of frequencies to obtain a quantity known as Integrated Polar Backscatter and comparing the Integrated Polar Backscatter with a reference value to determine if the Integrated Polar Backscatter represents a defective composite material.

5. The apparatus for non-destructive evaluation of the interior of composite materials with regular surface impressions according to claim 4, wherein said converting means is an analog spectrum analyzer.

6. The apparatus for non-destructive evaluation of the interior of composite materials with regular surface impressions according to claim 4, wherein said converting means is a digital computer programmed to perform Fourier transforms.

7. The apparatus for non-destructive evaluation of the interior of composite materials with regular surface impressions according to claim 4, wherein a digital computer is programmed to serve as the processing means.

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