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3H 1

FLAW CLASSIFICATION TECHNIQUES IN ULTRASONIC INSPECTION

CLASSIFICATION TECHNIQUE DES DEFAUTS DANS L'INSPECTION ULTRASONIQUE

INIS

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SUMMARY: Pattern recognition concepts and several sample problems are presented in flaw classification.

RESUME : Les theories de reconnaissance de plusieurs exemples sont presentés dans la classification des défauts.

I. ABSTRACT

I.1

With the increasing importance of nuclear power plant inspection, pressure vessel inspection for the energy industry, and rail inspection for the transportation industry, there has become an urgent need for the development of reliable and precise flaw classification techniques. Emphasis has recently been placed on studying ultrasonic response variations as a function of flaw type, shape, size and orientation. Frequency analysis has demonstrated some potential for solving problems of this type. The state of the art on this subject, however, is progressing very slowly because of the large number of parameters generally associated with flaw characteristics. Rather than study the many details associated with flaw characterization and correlations with ultrasonic response functions, the purpose of this paper is to consider flaw classification techniques based on concepts of pattern recognition. Several different single type flaw geometries have been fabricated by way of side drilled electro discharge machining in steel test blocks. The flaw types consisted of cylindrical, rectangular, and triangular shapes. Experiments were conducted with a Biomation 8100 analog to digital converter and a PDP 11/05 minicomputer system. Data acquisition techniques utilizing principles of flaw scattering from normal beam impingement were considered. The data was then analyzed and classified by observing various non-linear signal features.

I.2

The goal of the study is to separate the 10 test flaws into as many groups as possible, possibly 10, in serving as a feasibility study for further work in flaw cluster analysis and classification. The concept of simulearning is then introduced for solving more complex problems in flaw classification. Results show that the simulearning techniques combined with appropriate data acquisition procedures can prove quite valuable in ultrasonic inspection and that hope exists for solving the atrocious flaw characterization and classification problem. The oral presentation of this paper will include additional flaw situations, cluster classification concepts, and additional work in simulearning and pattern recognition.

II. INTRODUCTION

II.1

Much work in flaw characterization has been carried out recently. The subject of equivalent flaw measurements and the DGS approach (distance gain size) is reviewed by Rose and Schlemm [1]. The potential values of simulearning in flaw classification has been presented by Rose, et al [2]. Advanced techniques in pattern recognition are reviewed by Kanal [3]. Adaptive non-linear training networks for flat bottom hole characterization have been studied by Mucciardi, et al [4]. Many other investigators have studied theoretical and experimental scattering concepts, and others have studied selected aspects of frequency analysis. The purpose of this paper is to introduce additional concepts in adaptive pattern recognition that could be useful in complex problems of flaw classification. A 10 flaw sorting problem feasibility study is also presented that illustrates the preliminary work associated with the complex procedures of flaw classification.

II.2

Nondestructive testing areas are tremendously important in many areas of mechanics, materials, and physics. A sketch of the various study areas associated with nondestructive testing are presented in Table 1. Emphasis in this paper is related to the path of nondestructive testing through pattern recognition and finally to flaw classification. A proposed simulearning procedure that illustrates the computational techniques associated with the simulearning block of Table 1 is presented in Table 2. Careful analysis of the items presented in Table 2 is necessary if one is to approach systematically the problem of flaw classification, the goal of the work being to establish such classifier parameters as data acquisition method, linear transform, nonlinear feature set, prototype set and engineering classification parameters and discriminant function type that could be useful for some proposed inspection problem.

II.3

A working definition and description of simulearning is presented in the following paragraph. The technique of simulearning is a hybrid concept, integrating various aspects of analytical mechanics, wave propagation analysis, learning machine philosophies, various mathematical pattern recognition and signal processing techniques, and finally, human judgment. A simulearner can best be described as a logic system activated by a parametric input that searches for classifier parameters for solving specific flaw, material, or system classification problems in a computationally efficient fashion. Parameters related to this technique are fed into a numerical computation scheme or model that generates data representative of many real world flaw characterization problems. Large numbers of data sets are obtained either analytically, experimentally, or generated by some combined analytical-experimental technique. The amplitude-time signatures of the simulated flaw situations are then subjected to a class of fast linear (tensor) transforms, such as Fourier, Mellin, etc. This set of data forms the domain of definition for non-linear maps, the range being a pattern space. For example, amplitudes at N specified frequency coordinates of the Fourier spectrum may be used to generate a column vector or pattern with N entries. The simulearner will generate patterns of this nature using a class of known useful characteristics such as 6dB down points, the maximum amplitude over an interval, etc. The simulearner will sequence through these "pure" patterns and evaluate each derived set as to its separability into classes and the relevancy of these class divisions to the particular problem at hand. The simulearner will then investigate the utility of hybrid patterns, that is volumn vectors whose entries are disjoint in the sense that each is obtained from a different linear transform, followed by the non-linear feature extraction process mentioned above. Using the usual criteria of least amount of errors, that procedure, be it pure or hybrid, is selected which is most promising as a characterization of the problem at hand. The problem and the best procedure are then stored as a set being available then for further analysis and classification.

II.4

The understanding of theoretical physics and mechanics represents a crucial first step in the data acquisition problem. The inspection techniques that could be considered in a flaw classification problem are outlined in Fig. 1. Although many different data acquisition techniques for flaw characterization analysis are possible, brief reviews of three principal methods of inspecting from one surface only in a single plane are illustrated in Fig. 1. The scanning technique provides us with normal beam amplitude versus time profiles as a function of coordinate X. The echo dynamics technique or angle beam scan provides us with a signal amplitude versus X profile. Amplitude versus time profiles as a function of X could also be considered for this data acquisition technique. The scattering technique utilizes a normal beam probe at a fixed distance X_1, and a second probe as a function of X_2 that examines both the normal and shear wave scattering characteristics from the flaw being evaluated. The data acquisition technique considered in the sorting study is based on normal and shear wave scattering as indicated in Fig. 1c.

III. A SORTING PROBLEM FEASIBILITY STUDY

III.1

Flaw types considered in this study are presented in Table 3. The flaws were all manufactured by electrode discharge machining in steel blocks. Characteristics of the various flaws are presented in Table 4.

III.2

The data acquisition technique considered in this study is illustrated in Fig. 2. Transducer 1 was considered as the sending transducer to the flaw machined in the test specimen approximately 25 mm from the sending transducer. An angle beam transducer was used in position 2 to receive scattered normal and shear waves. The transducers used in this study were of 5 MHz center frequency with a 6dB down bandwidth of 3 MHz. The angle beam receiving transducer was rated at 45° in steel. The data was recorded with a Biomation 8100 analog to digital converter and stored in a PDP 11/05 minicomputer. The data points were stored along with the corresponding Fourier transform and phase angle. Sample results for one particular problem are shown in Fig. 3.

III.3

Although sorting aspects of this 10 flaw separation problem were considered from a somewhat advanced simulearning point of view, it was found that the solution techniques were quite simple in nature and required only a few of the non-linear features, the special features of which are presented in Fig. 2. The sorting procedure, found to work well for separating the 10 flaw specimens into 10 isolated regions, is outlined in Table 5. Scattered normal and shear wave data for the 10 flaws studied produced a double echo effect as indicated in Fig. 2. The gain or reflection amplitude values were not considered in this classification problem because of transducer contact surface area and couplant inconsistencies. Emphasis was therefore placed on obtaining other features of the signal that could separate the 10 flaws into 10 distinct regions in pattern space. Combinations of the parameters A_1, A_2, T_1, A_3, A_4, and T_2 were studied in detail. After several attempts at classification, it was found that the 10 flaws could be separated nicely by considering the parameters defined below.

- T_1 = principal separation and the sharp edge surface area parameter
- A_1/A_2 = sharp edge defect inclination parameter
- A_4/A_3 = sharpness parameter
- A_3/A_1 = cylindrical surface area parameter

The final sorting procedure for this problem is illustrated in Table 5.

III.4

An alternative approach to this "brute force" separation technique would be to define a pattern space of four dimensions over the feature parameters T_1, A_1/A_2, A_4/A_3, and A_3/A_1. A pattern would be a column vector with the first entry T_1, the second A_1/A_2, and so forth. Having defined the classification problem in the construct of a finite dimensional pattern space, standard pattern recognition procedures may be utilized. Using samples of known classifications from the 10 flaw classes, the relative importance or weights of the parameters with respect to classification can be determined. In this instance, there will be four weights. These weights will be used to construct a linear transformation which will carry the originally defined pattern space into a pattern space where predefined measure of pattern class simularity will be optimized. The classification problem then becomes a matter of transforming the flaw problem to the optimal space and classifying it. Since the transformation will be linear, it can be represented by a four by four diagonal matrix. Only ten prototypes, defined as the mean-value vector of a particular class, need be retained, and classification of test samples carried out by using a minimum distance discriminant function as a measure of similarity.

IV. CONCLUDING REMARKS

Results presented in this paper show that the application of the simulearning logic presented in Table 2 for flaw classification is a very promising one. Admittedly, the single flaw situations reviewed in this paper presented a very simple problem from a feature selection point of view. The real test of the method will lie in the more complex cluster analysis classification. The value of other transforms may be more apparent in the more complex problems of flaw classification. A best combination of linear transform and non-linear feature set may prove useful in solving the cluster classification problem. It might be pointed out that additional data acquisition may also be necessary. Additional aspects and results of the flaw cluster analysis problem will be included in the oral presentation of this paper.

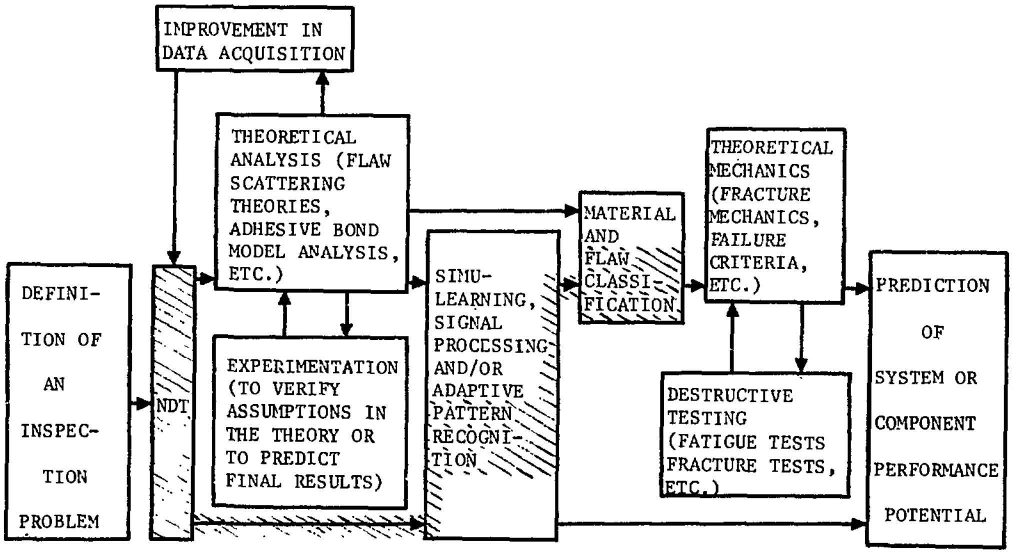


TABLE 1 - VALUES OF NDT IN THE MATERIAL AND FLAW CLASSIFICATION OR SYSTEM PERFORMANCE POTENTIAL PREDICTION PROBLEM

TABLE 2 - A PROPOSED SIMULEARNING COMPUTATION PROCEDURE

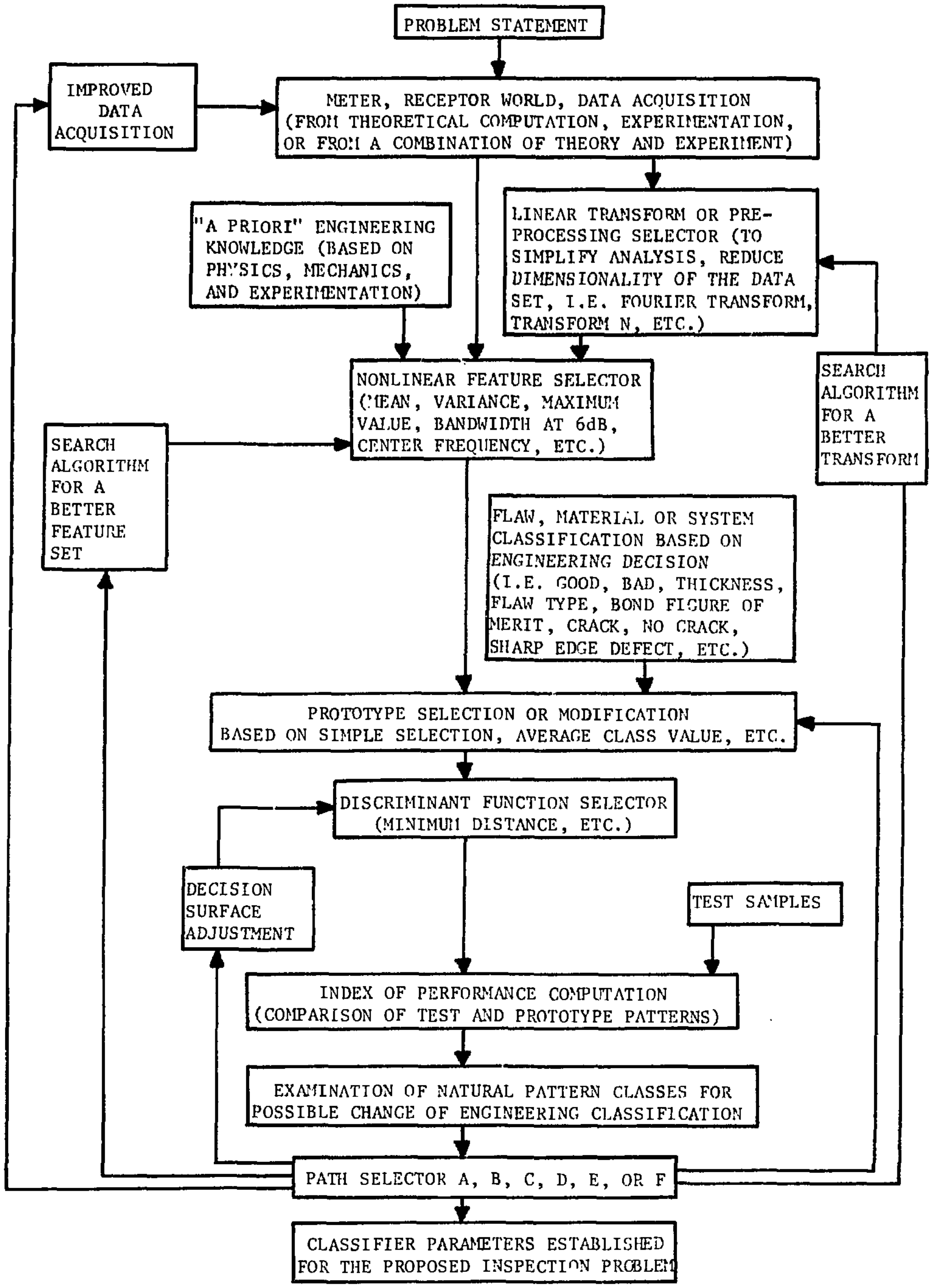
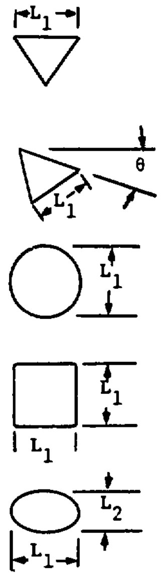


TABLE 3 - ELECTRO-DISCHARGE MACHINED SIDE DRILLED FLAW TYPES



Type 1	Normal Sharp Edge Defect
Type 2	Inclined Sharp Edge Defect
Type 3	Cylindrical Defect
Type 4	Rectangular Edge Defect
Type 5	Elliptical Defect

TABLE 4 - TEST SPECIMEN FLAW CHARACTERISTICS

FLAW NO.	TYPE	L_1(mm.)	L_2(mm.)	θ
1.	1	4.76	-	0°
2.	1	3.18	-	0°
3.	4	3.18	-	-
4.	1	2.38	-	0°
5.	2	3.18	-	30°
6.	2	3.18	-	45°
7.	3	4.76	-	-
8.	3	3.18	-	-
9.	3	1.59	-	-
10.	5	3.18	2.38	-

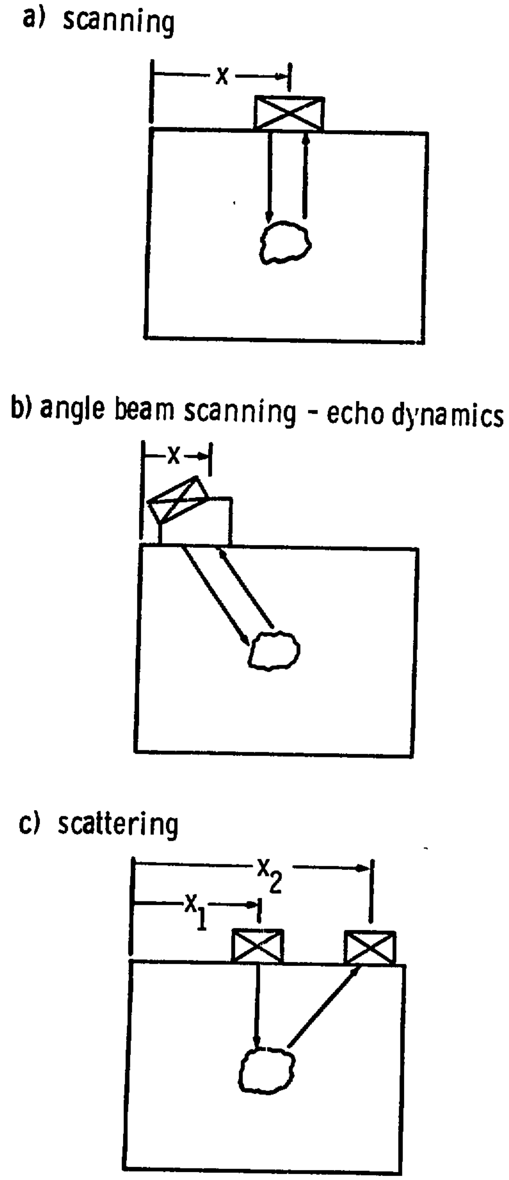
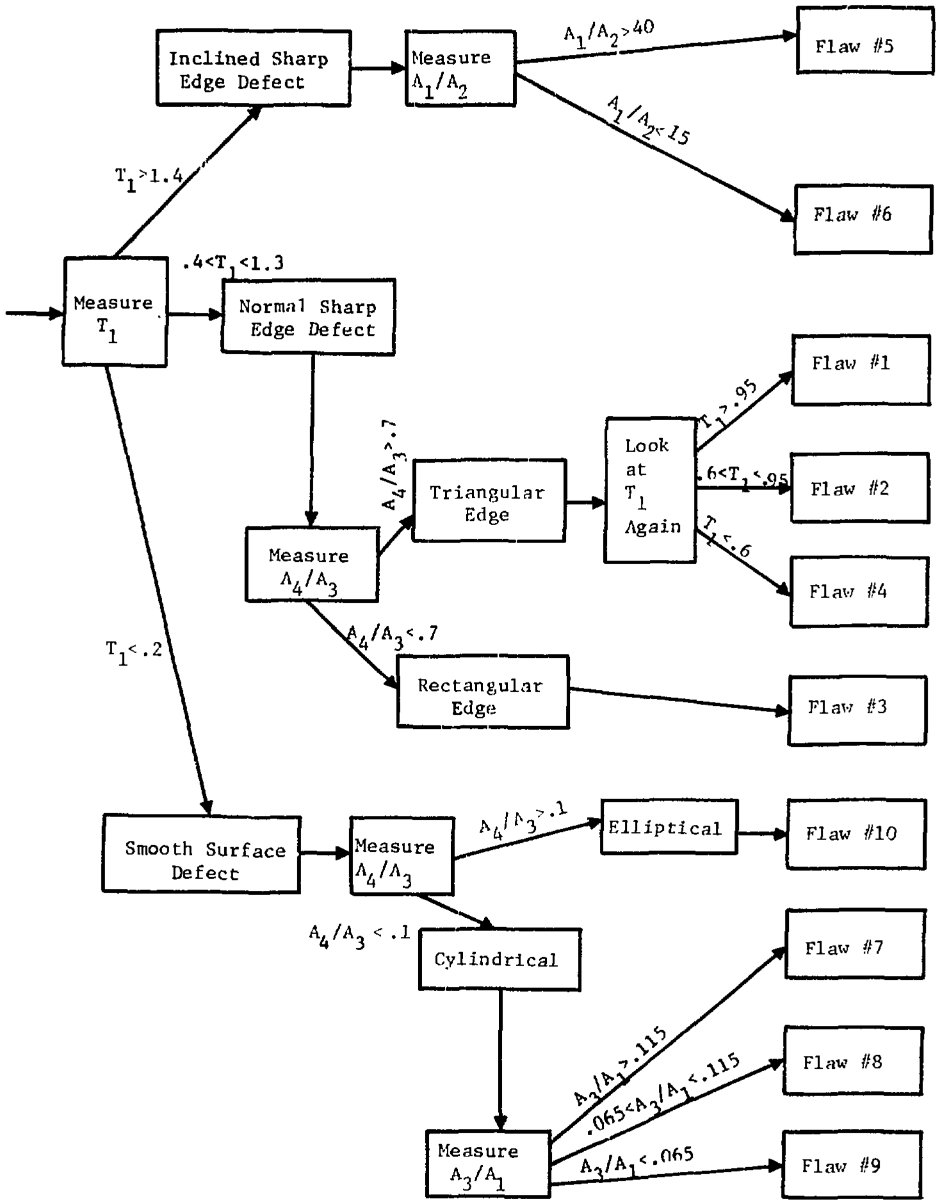
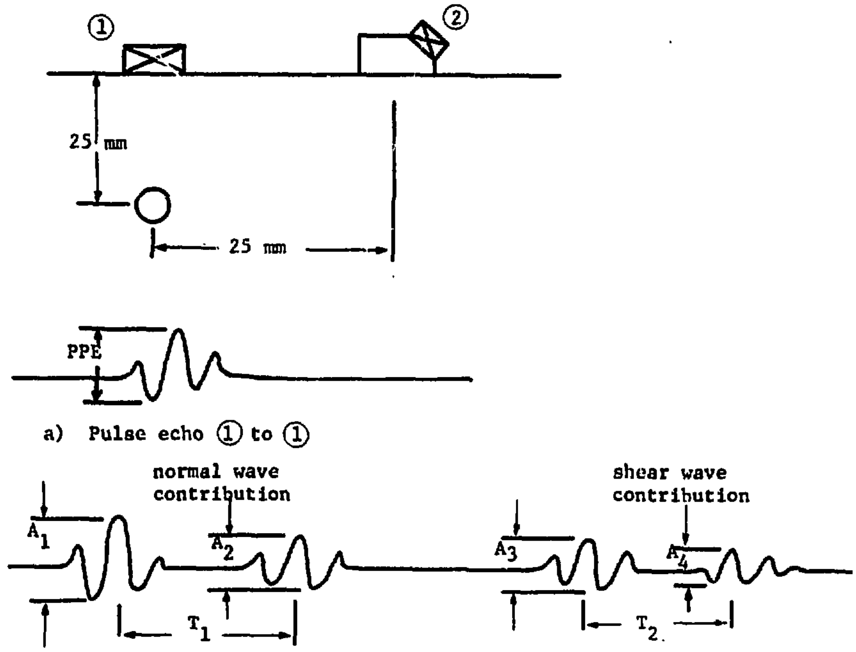


FIG. 1 - SUGGESTED INSPECTION TECHNIQUES FOR FLAW CLASSIFICATION

TABLE 5 - A SORTING PROCEDURE FOR THE 10 FLAW FEASIBILITY STUDY





b) Scattered normal and shear waves ① to ②

FIG. 2 - DATA ACQUISITION TECHNIQUE

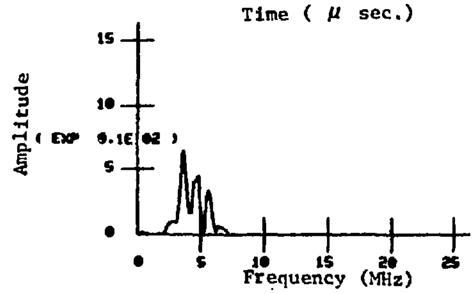


FIG. 3 - SAMPLE DATA RECORDING PROCEDURE (FOR FLAW #1, SCATTERED NORMAL WAVE)

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