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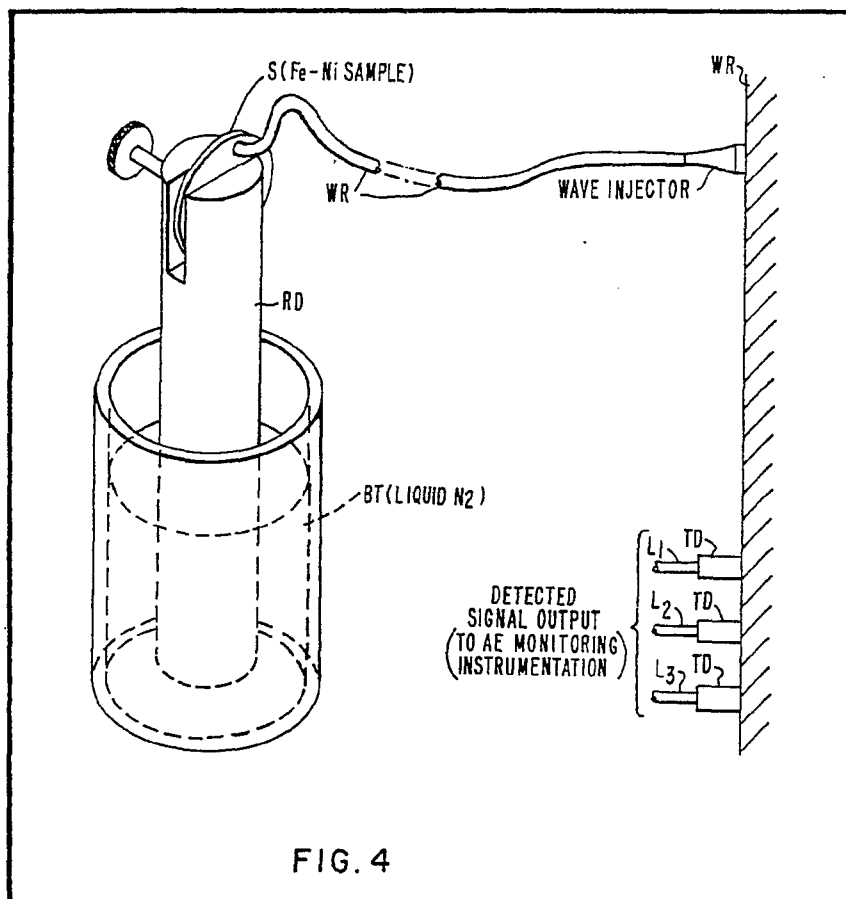
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(54) **Method and Apparatus for Generating Acoustic Waves**

(57) A portable source of acoustic waves comprises a sample (S) of iron-nickel alloy including an austenite phase cooled to become martensite, and a wave guide (WG) to transmit the acoustic waves. The source is applied to the pressure boundary region (WR) of a pressurized water reactor to simulate an actual metal flaw and test the calibration of the monitoring and surveillance system.

With at most 29.7% nickel in the sample, the source provides acoustic emission due to ductile deformation, and with at least 30% nickel the acoustic emission is characteristic of a brittle deformation. Thus, the monitoring and surveillance system can be tested in either or both situations. In the prior art, synthetic waveform signals were used for such calibration but found not suitable for on-line simulation of the surveillance system. This invention provides an improved system in that it generates true acoustic signals.



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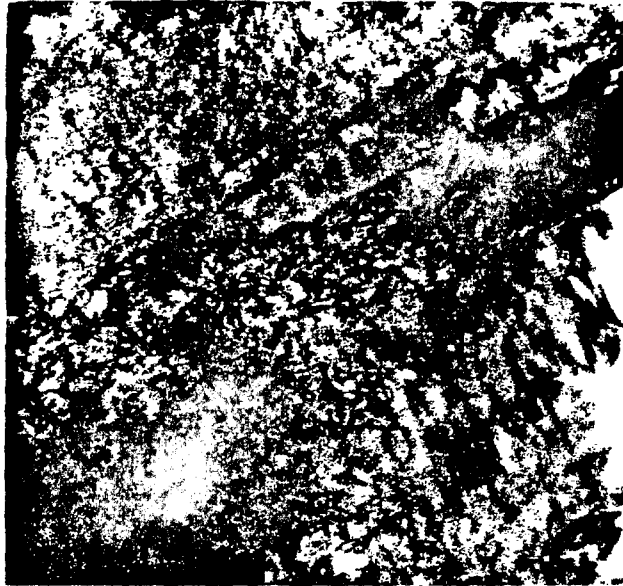


FIG. 1

(X 52,400)



FIG. 2

(X 30,100)

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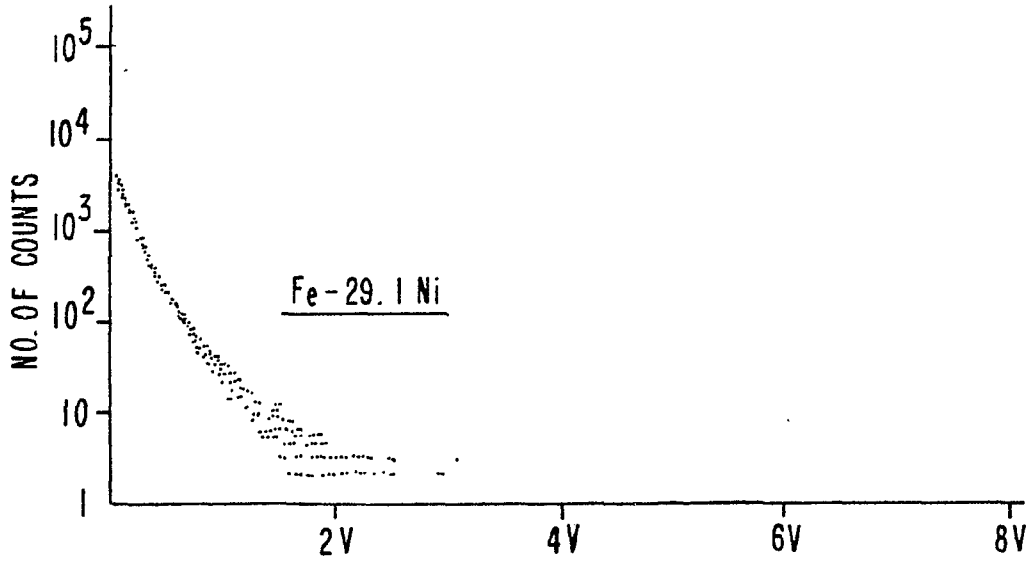


FIG. 3A

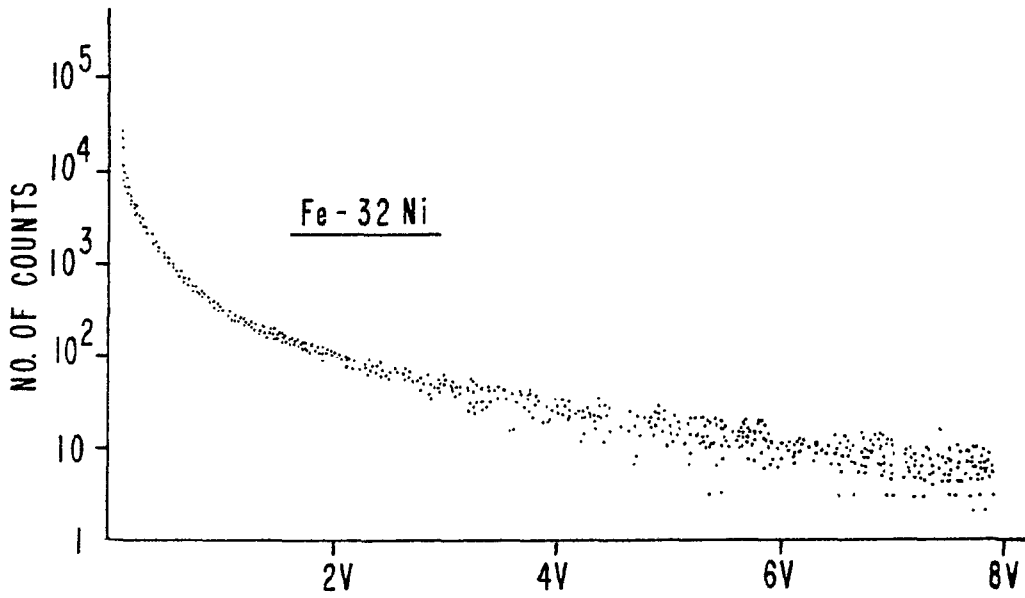


FIG. 3B

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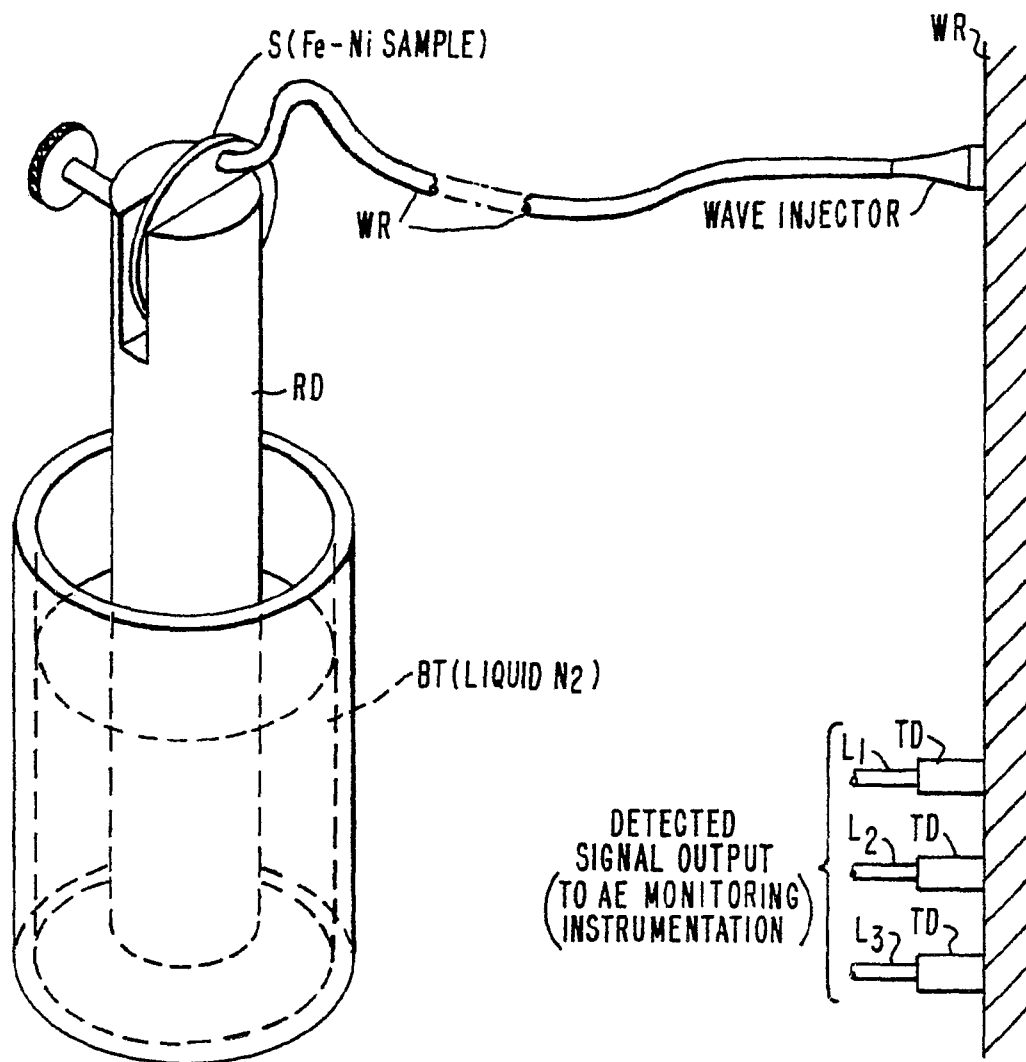


FIG. 4

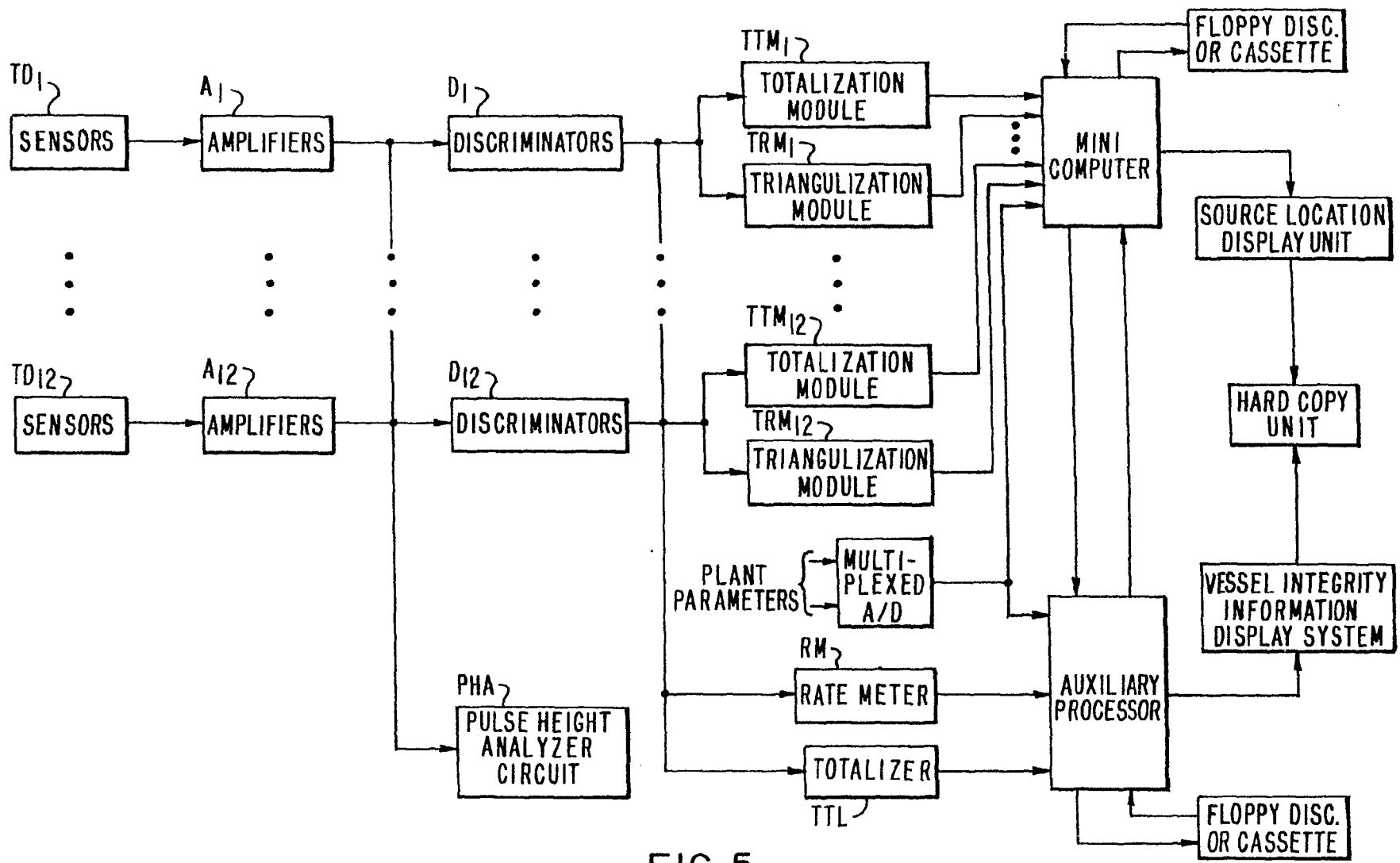


FIG. 5

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SPECIFICATION
Method and Apparatus for Generating
Acoustic Waves

This invention relates generally to an improved
 5 method and apparatus for generating acoustic
 waves and, more particularly, to a method and
 apparatus for the simulation of true acoustic
 signal of physical origin as can be used for on-line
 evaluation of an acoustic surveillance system. The
 10 invention is applicable particularly for crack and
 flaw monitoring with the vessel and piping of
 pressurized water reactor.

It is important with a pressurized water reactor
 installation to be able to reliably detect a flaw or a
 15 crack as it is formed or developing in the reactor
 vessel well before it reaches dangerous
 proportions. It is well known that such flaws or
 cracks which originate in metallurgical local
 defects, stresses or transformations cause an
 20 acoustic emission. Accordingly, it has been
proposed to install transducers for the detection
and location of the defects propagated through
the vessel wall through the detection of acoustic
waves. The difficulty lies in recognizing from the
 25 *transducer signal whether it originates in a true*
wall defect. To ascertain the nature of the signals,
the prior art utilizes an electronically synthesized
signal for comparison with the received signals.
 The weakness of such a technique lies in that an
 30 electrical waveform, which has no relation to a
 real signal of physical origin, is used as a
 standard. Such "synthetic" waveform signals,
 even as a simulation of acoustic signal, are not
 true acoustic signals, e.g. that are characteristic of
 35 material deformation. True acoustic signals are
 required for a periodic on-line evaluation of an
 acoustic surveillance system to ensure the
 detectability of incipient flaw growth at the
 pressure boundary of nuclear vessel or piping. It is
 40 not sufficient to use a signal generator for
 simulating acoustic signals, since it is unreliable
 to use signals of unknown physical origin or
 totally unrelated to the very event to be detected,
 namely, the energetics of a deformation zone in
 45 the metallic wall of a reactor vessel or in the
 piping.

Attempts have been made to generate
 predetermined true acoustic signals instead of a
 mere synthetic signal for the purpose of a
 50 standard comparison, but these have resulted in
 poor approximations.

Indeed, the effectiveness and merit of an
 acoustic monitoring system for pressure boundary
 integrity surveillance of a nuclear pressure vessel
 55 rest mainly upon its ability to identify acoustic
 signals generated as a result of material
 deformation accompanying flaw growth
 experienced by the vessel while the reactor is
 under operating conditions.

In the absence of a true signal available at the
 60 time of testing, an object of the present invention
 is to generate signals in situ and at will which will
 be caused by the deformation of a test sample of
 the same material as the vessel wall, or piping,

65 and to use such signals for evaluation of the
 monitoring and surveillance system. Attempting
 to generate such signals by deforming the test
 sample under mechanical means at the vessel site
 appeared highly impractical due to the problems
 70 involved in setting up a test rig at the site and in
 eliminating noise signals due to the system for
 mechanically loading the test rig. A simpler and
 more effective way of generating true acoustic
 signals appeared to be needed.

It is, therefore, an object of the present
 invention to provide an improved method and
 apparatus for generating acoustic waves with a
 view to overcoming the deficiencies of the prior
 art.

Another object of the present invention is to
 generate in a simple and more effective way
 acoustic waves from the deformation of a sample
 of metallic material.

Still another object of the present invention is
 85 to provide a portable source of acoustic waves
 due to the physical transformation of an alloy in
 the nature of a ductile deformation or of a brittle
 deformation.

Still another object of the present invention is
 90 an improved acoustic surveillance system for the
 early detection of flaws and crack formations in
 the piping or the vessel wall of a pressure water
 reactor, through the generation of true acoustic
 signals to be used as a standard of comparison
 95 with actual acoustic signals propagated through
 the piping or vessel wall under incipient flaw
 and/or cracks.

The invention resides in a method of
 generating acoustic waves representative of
 metallurgical deformation comprising the steps
 of: selecting a composition of iron and nickel; heat
 treating said composition to form an austenite
 phase; and cooling said composition to transform
 said austenite phase into martensite, whereby
 100 acoustic waves are generated during said
 austenite to martensite transformation step.

The invention also resides in an acoustic signal
 generator system comprising: a sample of metal
 alloy having a composition of iron and nickel with
 110 an austenite phase thereof; means for cooling
 said sample to substantially transform said
 austenite phase into martensite; means
 associated with said sample for propagating
 acoustic waves emitted by said austenite to
 martensite transformation toward a remote
 115 location; and transducer means for converting
 said propagated acoustic waves into acoustic
 signals.

In accordance with a preferred embodiment of
 120 this invention, there is provided an improved
 method and apparatus for generating acoustic
 waves which are representative of a deformation
 resulting from the growth of a structural defect, or
 flow, in a metallic wall which may be part of a
 piping or of a vessel in a nuclear installation.

To ensure reliability, the monitoring and
 surveillance system is periodically evaluated by
 making it respond to predetermined acoustic
 signals generated by known metal stresses

purposely developed and propagated through the vessel. With the assist of the occurrence of such predetermined acoustic signals imparted when desired, the monitoring and surveillance system

5 can be evaluated, checked, calibrated, or otherwise set in condition for the future detection of a true event, e.g., either a ductile deformation, which is less critical or a brittle deformation, which is more critical flow growth.

10 The method consists in selecting a composition of an iron-nickel alloy which has been heat treated to have an austenite phase and in cooling the composition so as to transform the austenite phase into martensite which causes deformation of the internal structure, thereby to emit acoustic waves. These waves are propagated through the piping or wall vessel to simulate in situ a metallic flaw when detected by transducers disposed against the piping or vessel wall.

20 When there is at most 29.7 % nickel, such austenite to martensite transformation simulates the formation of a substructure which is characteristic of the ductile flaw (less critical) growth in the piping or vessel wall, whereas with at least 30% nickel the transformation is indicative of a brittle (more critical) flaw growth in the piping or vessel wall.

30 A surveillance and monitoring system which involves a plurality of transducers placed at strategic locations on the piping or vessel wall, can be from time to time calibrated by means of metal samples cooled by the aforementioned method so that acoustic signals are detected by the transducers which simulate actual flaws. As a result, the integrity of the piping or vessel wall is verified by a surveillance and monitoring system which is effective and reliable at all times.

40 The invention will become readily apparent from the following description of an exemplary embodiment thereof when read in conjunction with the accompanying drawings, in which:

45 Figure 1 is a microscopic view of a metallurgical substructure developed during "lath" martensitic formation in an alloy of iron and 29.1% nickel;

50 Figure 2 is a microscopic view of a metallurgical substructure representing brittle deformation developed during "plate" martensitic formation in an alloy having iron and 32% nickel;

Figure 3A shows the amplitude distribution plot of acoustic emission signals characteristic of ductile (less critical) deformation as in the case of Figure 1;

55 Figure 3B shows the amplitude distribution plot of acoustic emission signals characteristic of ductile (less critical) deformation as in the case of Fig. 2;

60 Figure 4 shows the acoustic wave generating apparatus according to a preferred embodiment of the present invention;

Figure 5 shows circuitry which is typical of a vessel integrity monitoring system.

65 The invention is based on a systematic study of microstructural changes due to martensitic

transformation in Fe—Ni alloy systems and on the observation of the resulting acoustic emission.

70 A Fe-Ni alloy system has been selected because of two most favourable aspects: (1) in the course of its transformation such a system leads to a new structure induced by the generated deformation; (2) an initially stable phase exists at room temperature, namely austenite.

75 Passing from the initially stable phase to another phase by dynamic change is easily achieved through cooling of the austenite phase from room temperature. Typically, alloy samples used are ferrous alloys having a nickel content ranging from 29% to 32%. With such an alloy cooled, acoustic monitoring of the transformation occurring at low temperature has revealed a continuous emission of acoustic waves from the start to the end of the transformation.

80 Experiments conducted with alloys of different nickel percentages in the aforementioned range show that the amplitude of the detected acoustic signals increases with increasing amounts of the nickel content. Moreover, it was discovered by optical metallography study of the sample, that a morphological transition takes place when the proportion of nickel traverses a critical amount of 29.7% Ni. This critical amount delineates the passage of the martensite phase from "Lath" martensite below 29.7% Ni to "Plate" martensite above 29.7%. In this regard, a further study using electron microscopy has revealed that acoustic transmission with different samples experiencing these two kinds of transformations is due to a heavy dislocation when it is "Lath" martensite, whereas it is due to twinning internally with "Plate" martensite.

90 In accordance with the preferred embodiment of this invention, it is proposed to associate "Lath" martensite, or heavy dislocation, to the situation occurring when, in a vessel or piping, for instance, metal is experiencing flaw growth in a ductile (or less critical) manner, and to derive acoustic signals characteristic of such internal deformation as typical of an actual flaw of the same nature in real situation.

105 It is also proposed to associate "plate" martensite to the situation occurring when, in a vessel or piping, for instance, metal is experiencing flaw growth in a brittle (or more critical) manner, and to derive acoustic signals characteristic of such internal deformation as typical of an actual flaw of the same nature in real situation.

110 Figure 1 is a macroscopic view of "Lath" martensite (less than 29.7% of nickel) showing heavy dislocation as typical. Figure 2 is a macroscopic view of an internally twinned "Plate" martensite sample (more than 29.7% nickel).

115 It has been established that in the first instance, namely with Ni contents up to 29.7% of nickel, the transformation causes an acoustic emission which is representative of a heavy dislocation substructure. Hence, the emitted standard acoustic signal can be used as a standard signal to recognize in the plastic zone of

a reactor vessel, what typically is the plasticity of a growing flaw in a relatively tough matrix. It has also been established that, where the Ni content is above 30%, the emitted acoustic signal is symptomatic of twinning, e.g., should be characteristic of a brittle deformation like in a crack forming situation. For intermediate composition, e.g. with the Ni content lying between 29.7% and 30%, a mixed dislocation and twinning structure exists. In such case, acoustic emission is applicable to the detection of a signal representative of a mixed mode of deformation.

Referring to Figures 3A and 3B, the amplitude distribution of acoustic emission during transformation from austenite to martensite is shown as recorded for two Fe-Ni compositions of Figures 1 and 2, respectively.

A disc-shaped sample S of metal alloy of iron and nickel of selected proportion as explained hereabove, is heat treated to austenite condition. Sample S is, thereafter, mounted at one end of a copper rod RD, as shown in Figure 4, and the opposite end of rod RD is immersed into a bath of liquid nitrogen BT. By thermal conductance through rod RD, the temperature of sample S is progressively lowered from room temperature down to -270°F , the duration of cooling being in the range of 15 minutes to half an hour. In the process, austenite is converted to martensite. The phase transformation causes abrupt internal microstructural changes. These changes are transmitted acoustically by a wave guide WG onto the wall of the reactor WR, which is the pressure boundary region under surveillance. The acoustic waves generated are detected by the transducers TD of the surveillance system which are mounted on the surface of the pressure boundary WR. Thus, the microstructural changes are translated into acoustic signals of a duration varying between 50 and 200 milliseconds. Thus, the acoustic waves transmitted by the wave guide WG are converted into electrical signals representing true physical events. At least two specimens of alloy experiencing martensite transformation are preferably used, which, as explained herebefore, are 1) a percentage of nickel to iron of up to 29.7% for the simulation of a ductile (less critical) form of crack; 2) a percentage of at least 30% Ni, a composition for which the sample generates acoustic waves which are typical of a brittle (more critical) material change. The possibility is not excluded of using a sample in the range between 29.7% and 30% Ni in which case the same sample could be used to simulate either situations of a ductile and a brittle type of metal flaw.

The several transducers TD are judiciously placed against the wall of the vessel, or piping, and are part of a monitoring and surveillance system used to detect and locate the source of the generated acoustic waves due to a defect in the nuclear system. During simulation the acoustic waves generated are from the sample S experiencing structural transformation under cooling by bath BT, as just explained. After evaluation of the

monitoring and surveillance system and calibration with such simulated flaw detecting signals, transducers such as TD are in a position to detect, at any moment, an actual defect developing in the metal of the vessel wall or piping.

Referring to Figure 5, a monitoring and surveillance system is shown, which is typically responsive to twelve channels originating in twelve transducers $\text{TD}_1 \dots \text{TD}_{12}$. At any given moment, an acoustic emission signal of a particular intensity, duration and shape is received by one or all of transducers $\text{TD}_1 \dots \text{TD}_{12}$, amplified by respective amplifiers $\text{A}_1 \dots \text{A}_{12}$; passed through a discriminator ($\text{D}_1 \dots \text{D}_{12}$); processed by a totalization module ($\text{TTM}_1 \dots \text{TTM}_{12}$), and a triangularization module ($\text{TRM}_1 \dots \text{TRM}_{12}$). The rate is measured by a common rate meter RM. The total energy developed is measured by a totalizer. The overall information is compared, analyzed, logged, and more generally treated by a computer shown to include a minicomputer with the assist of an auxiliary processor.

Since the simulated signals obtained according to the system of the present invention have characteristics which are compatible with those of an actual signal due to an existing flaw, the monitoring system of Fig. 5 can be periodically run under simulation with samples such as S for the aforementioned two classes of defects.

The signals from amplifiers $\text{A}_1 \dots \text{A}_{12}$ due to the sample S or to an actual flaw being detected are inputted into a pulse height analyzer circuit PHA. Circuit PHA during simulation permits ascertaining that the system is in condition to provide signals which in the ductile deformation situation are like shown by Fig. 3A and in the brittle deformation situation are like Fig. 3B, thus in accordance with curves verified by laboratory experiments. Accordingly, whenever a real flaw occurs in the vessel or piping, the pulse height analyzer PHA will show a plot of the same nature as in Fig. 3A or Fig. 3B.

It is observed that while some effect is obtained with nickel percentages of much less than 29.7%, the maximum effect in terms of signal and duration is attained at 29.7% for the ductile deformation. On the other hand, above 30% e.g., in the range associated with a brittle deformation, the more nickel, the higher temperature at which the effect starts during the cooling is reduced. Therefore, at much higher percentages than 30% there may not be enough time available for calibration of the monitoring and surveillance system.

Claims

1. A method of generating acoustic waves representative of metallurgical deformation comprising the steps of: selecting a composition of iron and nickel; heat treating said composition to form an austenite phase; and cooling said composition to transform said austenite phase into martensite, whereby acoustic waves are

generated during said austenite to martensite transformation step.

2. The method of claim 1 wherein said metallic composition has at most 29.7% nickel, whereby the generated acoustic waves are typical of a ductile metal deformation.

3. The method of claim 1 wherein said metallic composition has at least 30% nickel, whereby the generated acoustic waves are typical of a brittle metal deformation.

4. An acoustic signal generator system comprising: a sample of metal alloy having a composition of iron and nickel with an austenite phase thereof; means for cooling said sample to substantially transform said austenite phase into martensite; means associated with said sample for propagating acoustic waves emitted by said austenite to martensite transformation toward a remote location; and transducer means for converting said propagated acoustic waves into acoustic signals.

5. An acoustic generator system as defined in claim 4, for use in monitoring the integrity of a metal piece under surveillance, wherein said propagating means propagates said emitted acoustic waves through said metal piece from at least one location thereof, said transducer means being coupled to said metal piece at least at another location thereof, whereby said acoustic signal is characteristic of acoustic wave propagated through said metal piece from said one location so said another location.

6. An acoustic generator system as defined in claim 4 wherein said metal piece is the wall of a

35 nuclear vessel, said transducer means including a plurality of transducers disposed at several said another locations against the wall of said nuclear vessel, with a vessel integrity system associated with said transducers for monitoring and

40 surveillance of said vessel wall, said vessel integrity system being calibrated with acoustic signals derived from said transducers during said austenite to martensite transformation of said sample.

45 7. An acoustic generator system as defined in claim 4, 5 or 6 wherein said sample has a percentage of nickel of at most 29.7%.

50 8. An acoustic generator system as defined in claim 4, 5 or 6 wherein said sample has a percentage of nickel of at least 30%.

55 9. An acoustic generator system as defined in claim 4, 5 or 6 wherein said sample has a percentage of nickel in the range of 29.7% to 30%.

60 10. An acoustic generator system as defined in claim 6 wherein a second said sample is associated with said cooling means and said propagating means, the first mentioned sample having a composition including at most 29.7% of nickel, said second sample having a composition including at least 30% of nickel.

65 11. An acoustic generator system as defined in claim 10 wherein a third said sample is associated with said cooling means and said propagating means, said third sample having a composition including nickel in the range between 29.7% and 30%.