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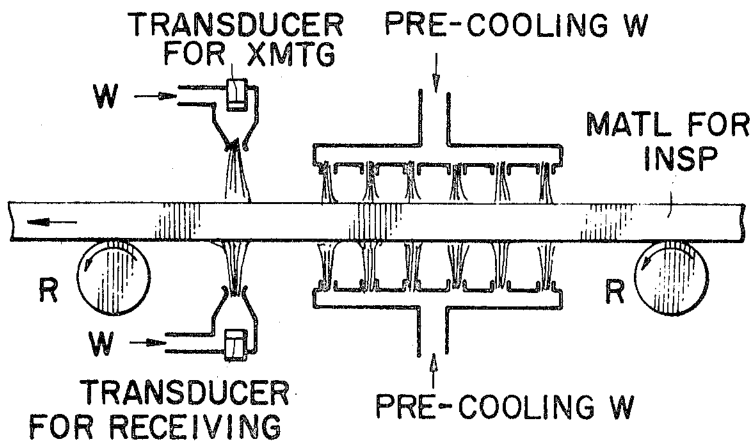
METHOD FOR CONTINUOUS SUPERSONIC INSPECTION OF HOT STEEL PLATES

Filed Sept. 25, 1969 5 Sheets-Sheet 1

SEARCH ROOM

FIG. 1 PRIOR ART



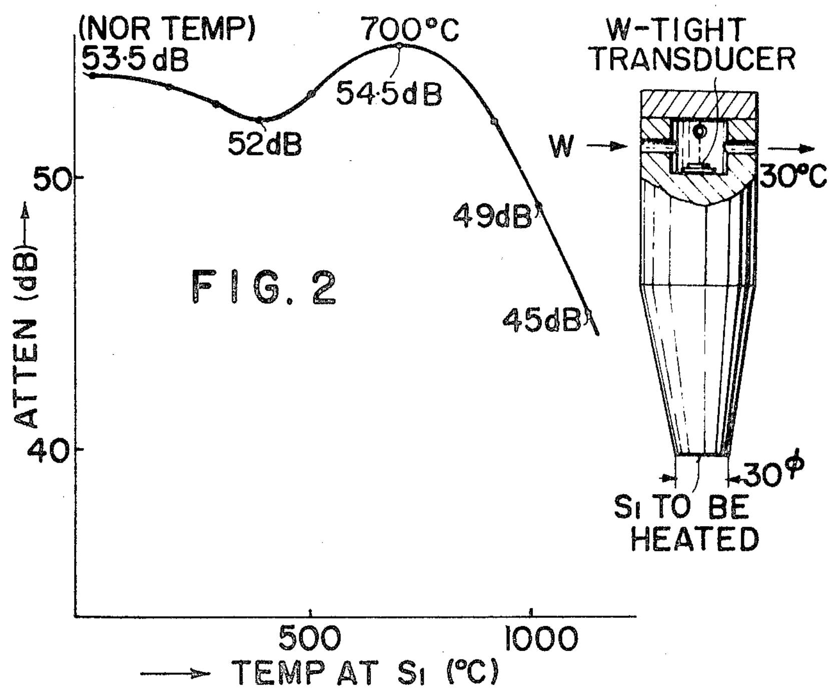


FIG. 2

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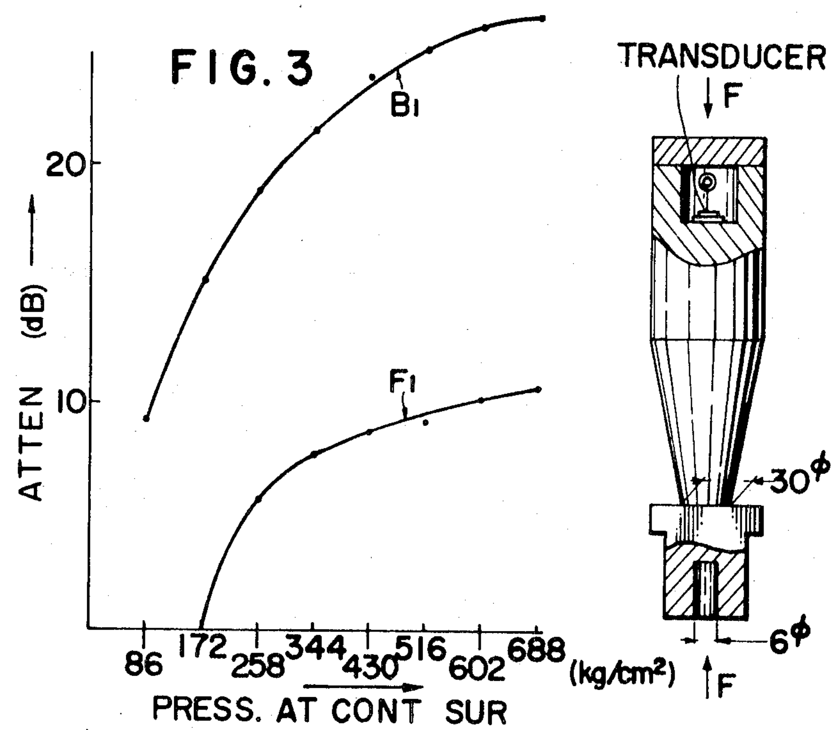

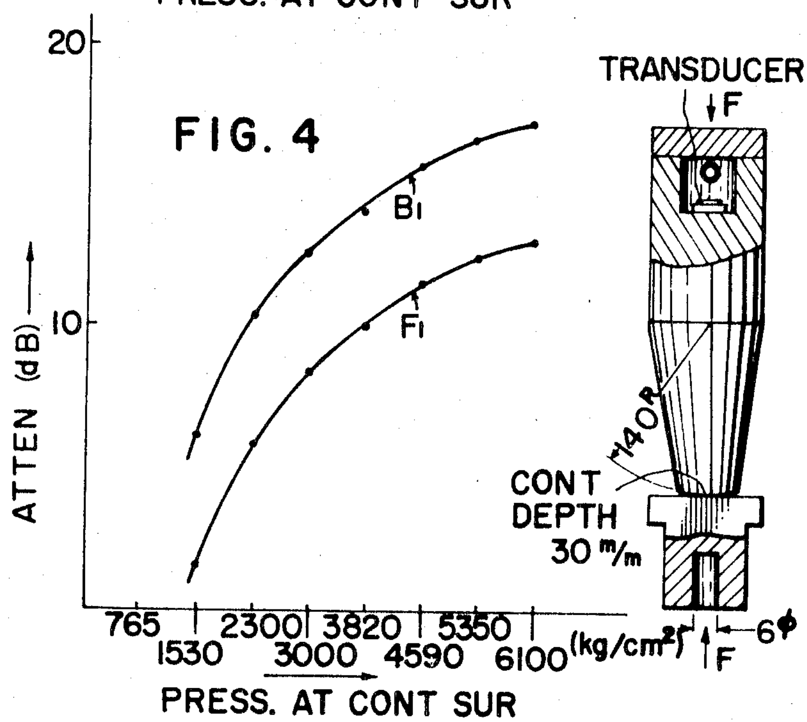

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FIG. 5

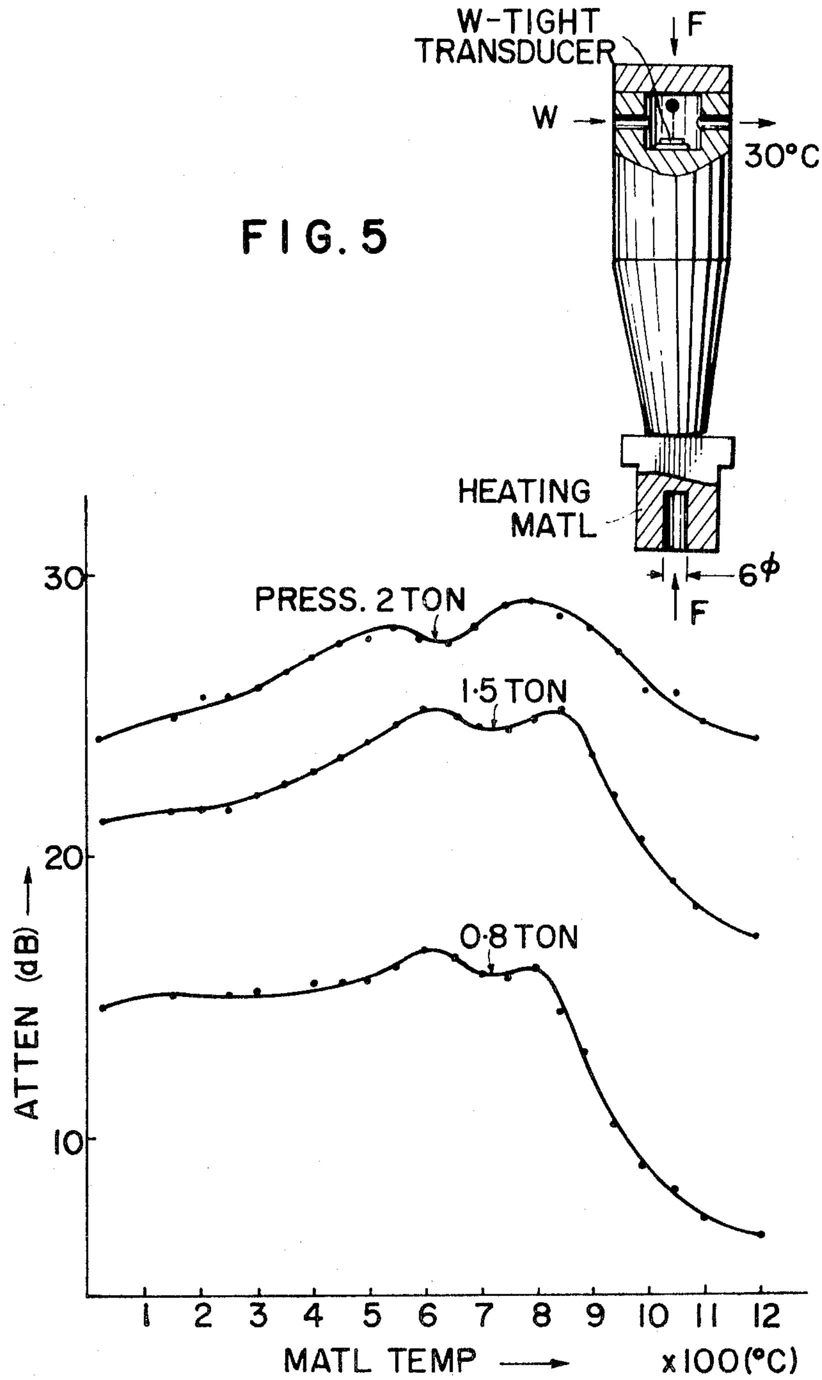

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FIG. 6

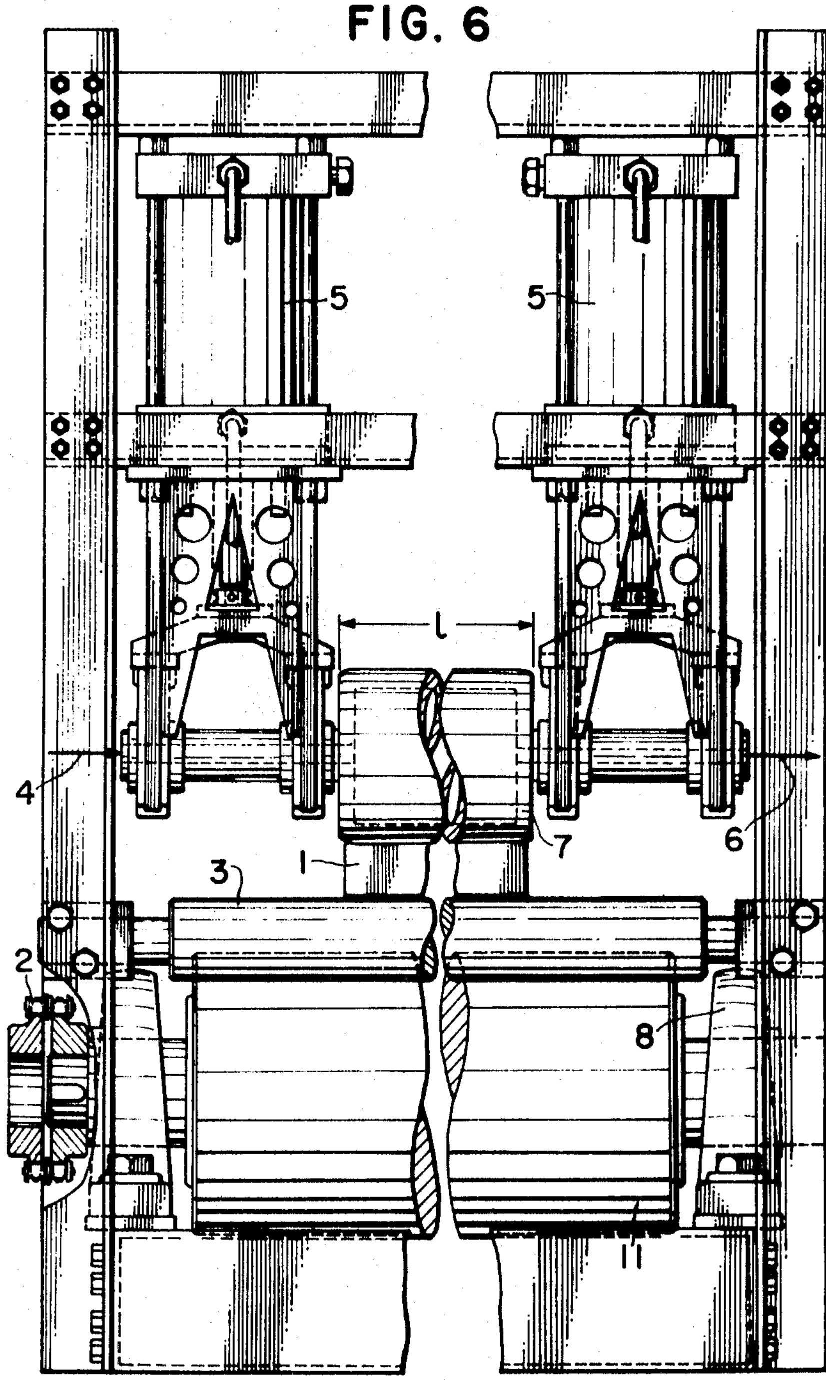

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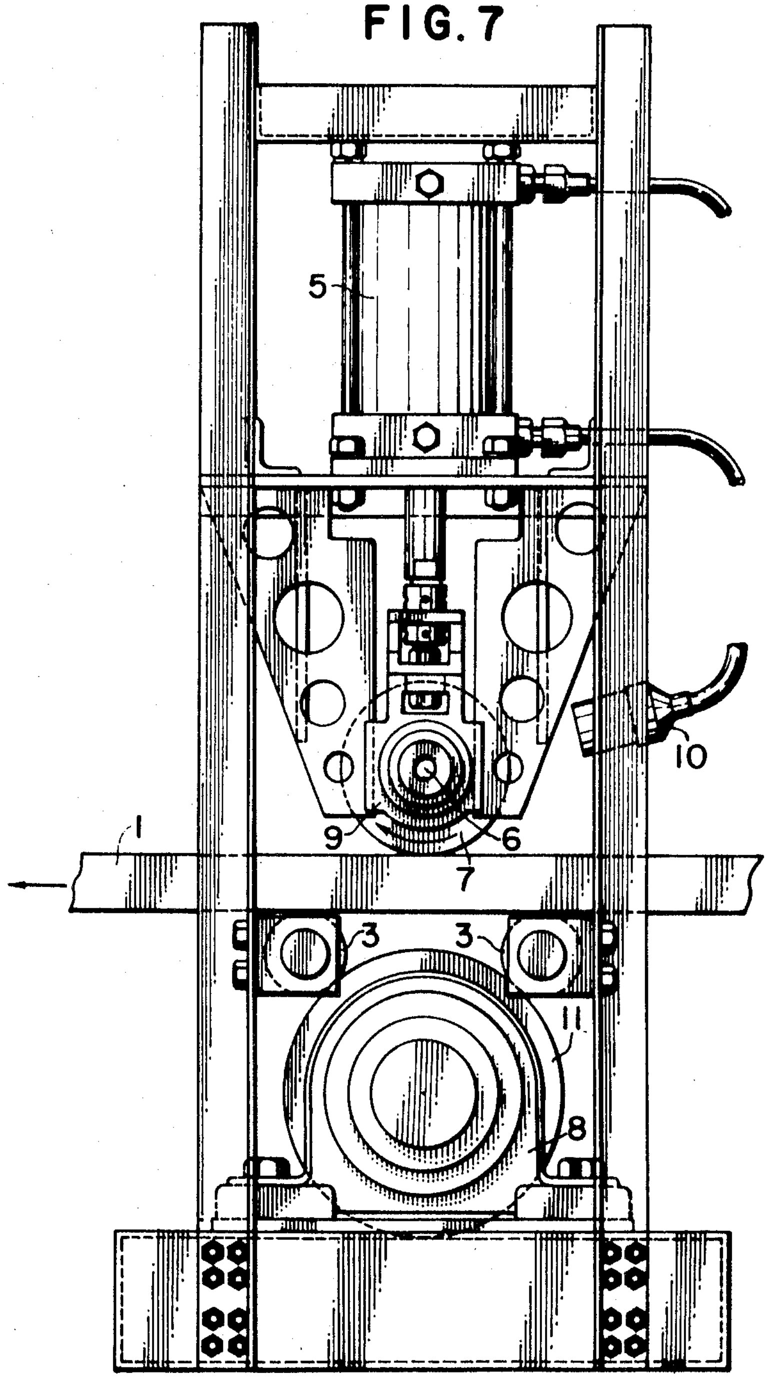
FIG. 7



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3,625,051
METHOD FOR CONTINUOUS SUPERSONIC INSPECTION OF HOT STEEL PLATES

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Int. Cl. G01n 29/00
U.S. Cl. 73—71.5 5 Claims

ABSTRACT OF THE DISCLOSURE

In detecting flaws in steel plates at a relative high temperature by ultrasonic signals, a steel material of the same quality as a steel plate to be tested is employed as an acoustic coupling, the steel material is formed into a cylindrical roller in order to perform continuous and automatic inspection, and a high pressure within the non-destructive range is applied to the steel material to realize an excellent acoustic coupling. Then the steel material is heated to prevent generation of an abrupt heat transfer impact.

BACKGROUND OF THE INVENTION

The present invention relates to a method for the continuous and automatic inspection of steel plates which are at a relative high temperature condition by means of ultrasonic, or supersonic, waves or pulse. The object of the invention is to provide a novel supersonic flaw detecting method which overcomes the limitations and other difficulties encountered in conducting the conventional methods for relative high temperature and high speed inspection which have been attempted hitherto, in order to make it possible to effect the continuous flaw detection of steel plates over an extremely wide scope of temperature, ranging between normal temperature and the level of about 1,200° C. This capability has long been demanded by the steel manufacturing industry.

In a known supersonic inspecting method, a jet, or stream, of water is utilized for attaining acoustic coupling. Basically the fundamental principle of the water stream jet method resides in acoustic coupling by use of a liquid. In other words, it is intended to achieve acoustic wave propagation between a liquid phase and a solid phase, eliminating the presence of any gaseous phase medium. However, as temperature of the steel plate being tested is raised over a certain level, the conduction of heat from the steel plate to the water stream is sharply promoted, and a water-gasifying area is produced close to the testing steel surface. As a result, a mingled area of gas phase and liquid phase which is most undesirable for acoustic coupling would be produced, and this invited generation of abnormal noises made it impossible to detect flaws in a steel plate at a temperature over said range. Further, the case of using a water jet as an acoustic coupling means, there is produced another difficulty which cannot be physically overcome in achieving the primary object in liquid phase contact; the critical temperature and critical pressure of water are 374.1° C. and 218.5 atmospheres pressure (a.p.) respectively, and its density under these conditions is 0.324 gr./cm.^{3}. (See International Critical Table or Chronological Table of Physico-Chemistry 1968, Material 68.) In other words, theoretically speaking, unless the temperature of the steam layer produced at the boundary face between the water and a hot steel surface is kept below 374.1° C. it is impossible to eliminate the gaseous layer and produce an interfacial condition desirable for acoustic coupling; i.e. where water of liquid phase and steel of solid phase would be contacted with each other, no matter how

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much the pressure is increased. Here exists the fundamental temperature limitation for supersonic inspection by means of a water stream jet. Therefore, in order to inspect steel plates having a higher temperature than this limitation by this method, it is required to reduce the temperature of the inspecting area of the steel surface below said limitation temporarily, at least during the inspecting operation, through a pre-cooling means.

On the other hand in order to suppress the generation of the steam phase at the interface, it is required to provide a pressure of more than 1 a.p. at 100° C., more than 4.698 a.p. at 150° C., more than 15.34 a.p. at 200° C., more than 39.23 a.p. at 250° C., and more than 163.2 a.p. at 350° C. (See Chronological Table of Physico-Chemistry 1968, Material 69), so that it is extremely difficult to realize an ideal interfacial contacted condition between liquid phase and solid phase at a relative high temperature area by using a water stream. Therefore, supersonic inspection has conventionally been conducted under the presence of a steam layer having a sufficiently small thickness when compared with the length of the supersonic waves used. Moreover both the unstable variation in thickness of this steam layer produced by a relative high speed feeding of steel plate and the sudden heat transfer transient impact appearing the moment the water jet impinges on the hot steel surface are considered as the primary factors which cause the generation of the abnormal noise signal witnessed in the inspecting operation for the relative high temperature steel plate by the conventional method. (See "Study Report on Automatic Supersonic Inspection for Thick Plates," pages 133–134 and page 143, published by the Learning and Study Advancement Society of Japan.)

There is, additionally, great difficulty in the practical aspect; namely, the attempt to raise up higher the pretended upper limit of the temperature range where inspection is conducted by using pre-cooling results in producing a great deal of steam, since more cooling water impinges on the surface of a steel plate having a huge heat capacity, and the steam then hangs over the testing field and causes excessive rusting of the steel plate.

As set out above, the conventional method using a water jet is accompanied with several difficulties which make it quite impossible to perform supersonic inspection under the condition of high temperature i.e. ranging up to about 1,200° C. Indeed, there is reported an example where steel inspection was successfully achieved in and at a temperature in which salt is molten by using molten salt instead of water as an acoustic coupling means. However, the use of molten salt as an acoustic coupling means for continuous and automatic inspection has never been practised partly due to economical disadvantage and partly due to difficulty in the removing operation of said salt.

SUMMARY OF THE INVENTION

It is a desired object of the present invention to surmount such limitations and difficulties as observed in the conventional methods and provide a novel method for continuous inspection under a wide range of temperature, i.e. between normal temperature and 1,200° C., which has long been awaited by the steel manufacturers.

This object is achieved according to the present invention by using as the acoustical coupling a steel material of the same quality as the steel plate being tested. Either echo pulse or through transmission ultrasonic pulse systems may be used, and the steel material may be in contact with one surface or a pair of opposing surfaces of the plate being inspected.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic side view illustrating a representative example of the conventional hot steel plate inspection system wherein a water stream is utilized as an acoustic coupling means.

FIG. 2 is a graph showing a plot of supersonic wave attenuation with the growth of temperature gradient in a steel material.

FIG. 3 is the graph showing a plot of flaw detection sensibility versus pressure at normal temperature in plane-to-plane contact.

FIG. 4 is the graph showing a plot of flaw detection sensibility versus pressure at normal temperature in cylindrical face-to-plane contact.

FIG. 5 is the graph showing a plot of flaw detection sensibility as a function of the testing material's temperature in cylindrical face-to-plane contact with and under pressure.

FIG. 6 is a front elevation view of an example of a practical device employed in applying the present invention.

FIG. 7 is a side elevation view of the device of FIG. 6.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 of the drawings shows schematically an example of a prior art ultrasonic inspecting system. In FIGS. 1, 2 and 5, W is used to designate "water"; and in FIG. 1 R designates rollers.

FIGS. 2 to 5 show graphs which were made under the condition that the graduation of the vertical axis (dB) was the value indicated at the attenuator when the amplitude of the echo pattern which is of the bottom or of an artificial flaw of 6ϕ flat bottomed on a cathode ray tube was a constant value of, for example, 50 mm.

The curves "B1" and "F1" shown in FIG. 3 and FIG. 4 denote respectively back echo character and flaw echo character.

Referring first to FIG. 2, it should be noted that the primary factor which has made flaw detection of relative hot steel plates by ultransonic, or supersonic signals impossible is not the temperature dependency of the supersonic wave attenuation in the steel material, but the unsuitability of the acoustic coupling means. As shown by the graph in FIG. 2, it was confirmed that any supersonic wave attenuation large enough to make flaw detection impossible is not produced even if there exists a heavy temperature gradient ranging between the normal temperature of 30° C. and the high temperature of 1,200° C., where the steel material becomes clear orange-colored in a identical steel material.

It has thus become evident that the problem resides in the method for acoustic coupling of the interface S_1, where the supersonic wave comes in and out. The present inventor has solved this problem in the following manner based on the next two facts; one is that, in general, the optimum condition for penetrating a supersonic wave from medium A to medium B is obtained when acoustic impedances, i.e. the density x times the sound speed, of both media are equal. The other is, the above-mentioned fact that the variation of supersonic wave attenuation is within only few dB at most, even if such a heavy temperature gradient as that between 1,200° C. and 30° C. should exist in the identical steel material. Based on these two facts, the inventor has attained the idea of using a steel as a material which is inserted between the transducer and the surface of testing steel plate to form a temperature gradient, hereinafter referred to it as "temperature gradient delay line material," and strongly pressing both steel materials toward each other with a force "F" so as to remove the interfacial gas phase and thereby achieve excellent acoustic coupling. The practicability of the idea is demonstrated by the graph shown in FIG. 3 which is based on an experiment.

Then, for conducting continuous inspection, the configuration of the temperature gradient delay line material is shaped into the form of hollow cylindrical roller so as to roll on in contact with a material to be tested. Moreover a high pressure is applied to the contacting faces to remove the interfacial gas phase and realize an excellent acoustic coupling. However, it is a basic rule that the high pressure is within the non-destructive range, so as not to produce any injurious deformation or deterioration of the quality of the material to be tested. For composing a supersonic wave transferring system between the stationary part of the roller, in which the transducer and the movable part of the roller, some suitable means may be employed; for example, a cooling oil may be circulated through said hollow cylindrical roller, and an oil-tight transducer placed on a pedestal and mounted to the central fixed shaft of the roller. The central fixed shaft has a leaf oil film between said pedestal and the inner face of said roller, and the pedestal serves as both the temperature delay line material and a lens which concentrates supersonic beams on the surface of the steel plate being tested. The efficiency of the means for continuous inspection mentioned above is confirmed by the graph shown in FIG. 4 which is also based on an experiment.

In addition, as a measure to arrest an abnormal transient signal which is likely to be produced at the moment of contact between the acoustic coupling material and the hot steel plate being tested in the case of relative high-speed and temperature inspection, an arrangement is made such as to prevent generation of abrupt heat transferring impact from said steel plate toward the roller of the temperature gradient delay line material at the moment of contact. Namely, this problem can be solved by approximating the surface temperature of said roller to the one of said testing steel plate. According to this method, the noise produced at the contact moment, as shown in FIG. 5, is so small that it may hardly be perceived.

An example of the mechanical composition of the device used in applying the present invention is embodied as shown in FIG. 6 and FIG. 7, wherein **1** denotes a steel plate to be tested, **2** a chain coupling, **3** a table roller, **4** a water introducing part, **5** an oil pressure cylinder, **6** a water discharging part and high frequency cable, **7** a cylindrical roller (housing a transducer therein), **8** a bearing, **9** take-up units (only one of which is shown) and **10** a heating burner. Axial length l of the cylindrical roller **7** may be suitably selected as the circumstances demand. For example, when it is desired to attain uniformity of the inspection, an elongated cylinder arranged such as to cover the entire width of steel plate **1**, shown in FIG. 6, may be formed by a suitable means, e.g. by using suitable back-up roller **11**. In such a case as using an elongated cylindrical roller, multi transducers may be arranged in the roller as the number of channels demanded.

As understood from the foregoing description and the accompanying drawings, the present invention is an effective one providing a continuous supersonic inspecting method for hot steel plates whose temperature may range between normal temperature and 1,200° C.

It should be understood that the above described supersonic inspecting method for steel plates may be used not only for a single transducer system wherein signal transmission and reception are effected by the same transducer on one side of the testing steel plate according to a pulse echo, but for a two-transducer system wherein signal transmission and reception are respectively effected by a different transducer, or for a signal penetration system wherein signal (pulse wave or continuous wave) transmitting and receiving transducers are respectively provided at both sides of the testing steel plate. FIG. 6 and FIG. 7 show a device employing the pulse echo system.

As various changes might be made of the above device used in applying the present invention, it is to be understood that all matter herein set forth or shown in the accompanying drawings, is to be interpreted as illustrative and not in a limiting sense.

What I claim is:

1. In a method for the continuous ultrasonic flaw inspection of steel plates having a surface wherein ultrasonic signals are transmitted into and received from a plate to be tested through an acoustical coupling, the improvement comprising the step of utilizing an element, of the same quality steel as the plate, as the acoustical coupling by putting it in contact with the surface of the plate, and the step of heating the element with a suitable heater prior to putting it in contact with the surface of the plate so as to prevent generation of abrupt heat transfer impact by approximating in the element the temperature of the plate.

2. The method of claim 1 wherein the ultrasonic signals are transmitted and received by a single transducer.

3. The method of claim 1 wherein the ultrasonic signals are transmitted by a first transducer and received by a second transducer.

4. The method of claim 1, the improvement further including the steps of shaping the steel element into the form of a hollow cylindrical roller, with a central, fixed shaft, circulating cooling oil through the hollow roller, placing an oil-tight transducer on a pedestal mounted to the central, fixed shaft of the hollow roller, the pedestal having a leaf oil film between the pedestal and the inner face of the hollow roller and serving as both a preceding temperature delay line material and a lens which concentrates ultrasonic beams onto the surface of the steel plate to be tested, which plate is being advanced continuously by combined action of the hollow cylindrical roller and at least one table.

5. The method of claim 1, the improvement further including the step of applying pressure to the steel element and the steel plate by means of a fluid cylinder, so as to press the element and plate together and eliminate the interfacial gas phase between them, the pressure used being within the non-destructive range of the material so as not to produce any injurious deformation or deterioration of the quality of the plate being tested.

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73—67.8, 67.1