

Oct. 3, 1950

W. E. PIPER

2,524,208

METHOD OF DETECTING FLAWS IN SOLID BODIES

Filed June 29, 1946

2 Sheets-Sheet 1

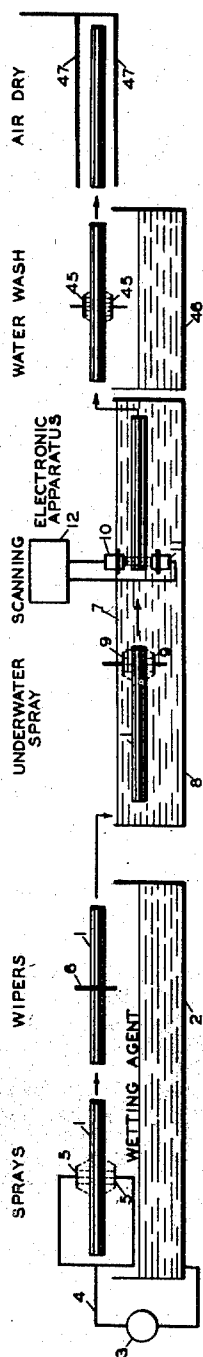


FIG. 1

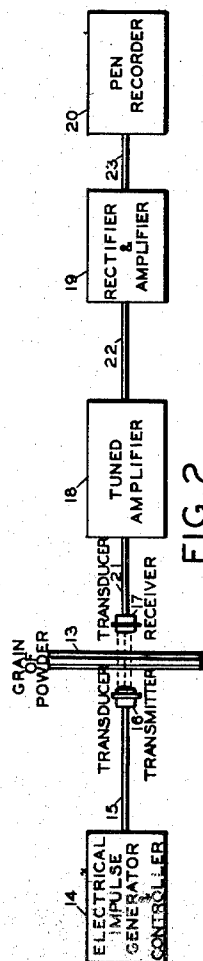


FIG. 2

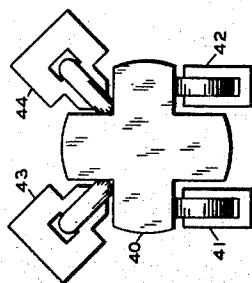


FIG. 3

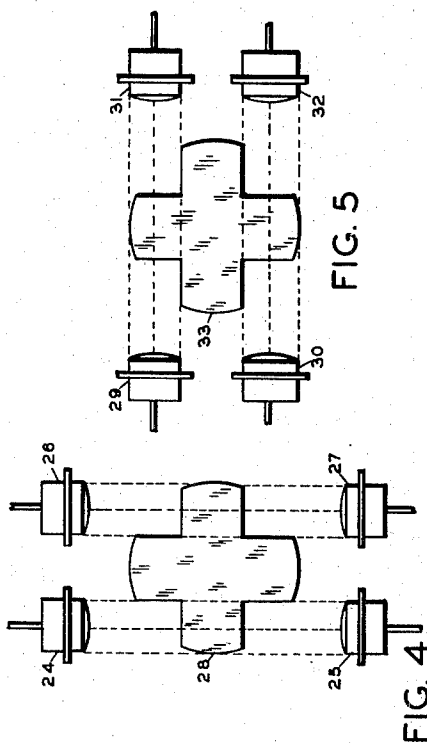


FIG. 5

FIG. 4

WILLIAM E. PIPER  
INVENTOR.

BY

*Ernest G. Peterson*

AGENT

Oct. 3, 1950

W. E. PIPER

2,524,208

METHOD OF DETECTING FLAWS IN SOLID BODIES

Filed June 29, 1946

2 Sheets-Sheet 2

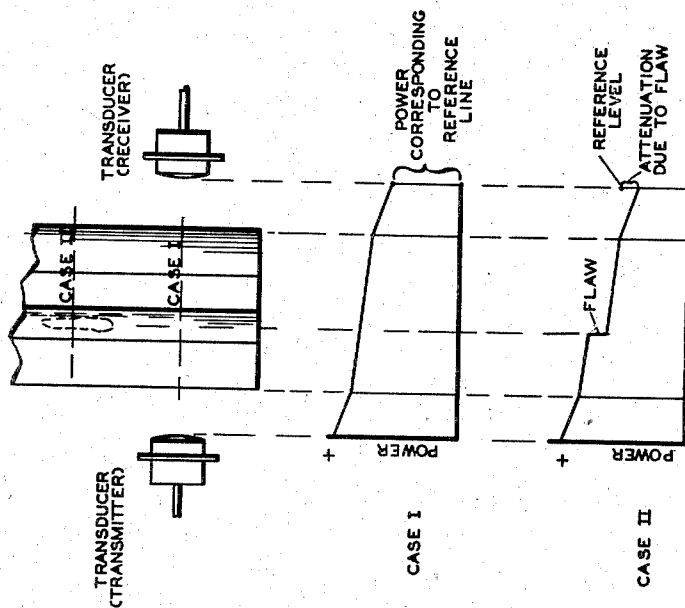


FIG. 8

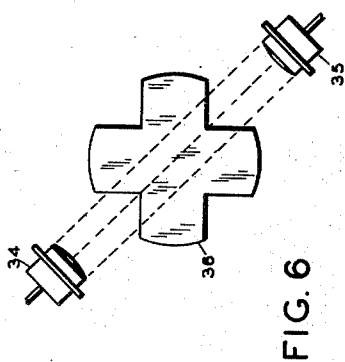


FIG. 6

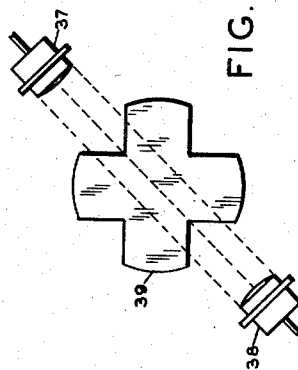


FIG. 7

WILLIAM E. PIPER  
INVENTOR.

BY

AGENT

## UNITED STATES PATENT OFFICE

2,524,208

METHOD OF DETECTING FLAWS IN  
SOLID BODIES

William E. Piper, Wilmington, Del., assignor, by  
mesne assignments, to the United States of  
America, as represented by the Secretary of  
War

Application June 29, 1946, Serial No. 680,363

7 Claims. (Cl. 73—67)

1

This invention relates to the manufacture of smokeless powder and more particularly to an improved method and apparatus for detecting imperfections and flaws in grains of colloid smokeless powder.

In the manufacture of large grain rocket powder commonly called "stick powder," sheets of colloid smokeless powder are rolled into tight rolls, commonly called "carpet rolls" and then pressed, at an elevated temperature, through a precision die. The thick strand of powder, which is thus extruded, is then cut into desired lengths and is ready for use. In the pressing operation, there is sometimes an unavoidable occurrence of small flaws such as bubbles, fissures, cracks, etc., in the extruded strand of powder. When such a flaw is exposed by burning it offers increased burning surface which causes a rapid acceleration of burning of the smokeless powder with a consequent abnormal, dangerous rise in pressure. In some cases, and particularly where burning starts in a flaw completely surrounded by powder, the pressure generated will in all probability cause the stick to disintegrate. This shattering further increases the burning surface, temperature and pressure, and fragments of the stick may plug gas passages. As a result, the firing of these sticks is particularly hazardous and produces an unpredictable trajectory of the rocket.

It is, therefore, important that these faulty sticks of powder be detected and separated from the good ones. One method, which has been utilized, involves the use of X-rays. Each individual stick of powder is X-rayed and the negative obtained examined by trained operators to pick out the sticks which are faulty. This method has not proven entirely satisfactory due to the various interpretations which may be placed on the X-ray pictures in some instances and to the extreme difficulty, if not impossibility, of detecting small flaws. Furthermore, X-ray examination is tedious, time consuming and expensive.

Another method which has been tried involves the use of a fluoroscope. This too has proven unsatisfactory because of the impossibility of detecting the small internal flaws.

Still another method which has been attempted involved scanning the stick of powder in air by means of ultrasonic sound waves. This too proved unsatisfactory due to the attenuation of sound waves in air, and the density difference between air and powder.

In accordance with the invention described hereinafter, the above difficulties have been over-

2

come by an efficient, economical, sure and safe method and apparatus for the detection of faulty sticks of smokeless powder.

It is therefore an object of this invention to provide a method and apparatus which will overcome the disadvantages of prior art methods and devices. It is a further object of the invention to provide a method and apparatus for surely detecting flaws in colloid smokeless powder sticks and which will not damage the stick nor subject the operators to undue hazard. It is a still further object of the invention to provide a sensitive, rapid and economical method and apparatus for scanning a smokeless powder stick immersed in water by the use of ultrasonic sound waves. Another object of the invention is to provide for the elimination of bubbles from the surface of the stick, while immersed in water, and during the scanning operation. Still another object of the invention is to eliminate the possibility of faulty sticks of smokeless powder being overlooked and utilized in firing, with consequent hazards and inaccuracy. These and other objects will be apparent herein as the description proceeds.

These objects are attained, in accordance with the present invention, by the use of a continuous process involving (1) wetting the smokeless powder sticks with a suitable wetting agent, (2) removing the excess wetting agent, (3) immersing the stick in a water bath of a specified temperature, (4) spraying the stick with an underwater spray to remove adherent bubbles, (5) scanning the stick, while immersed, by the use of high frequency ultrasonic waves, (6) recording the changes in attenuation of the ultrasonic waves in passing through the stick, (7) removing the stick from the water bath and washing it, and (8) drying the grain. It is known that ultrasonic waves have been used for detecting certain objects under water such as submarines, etc., and for testing rubber tires as disclosed in U. S. Patent No. 2,378,237 to Wilford E. Morris. These methods and devices usually employ low frequency, sonic and ultrasonic waves for specific uses with which this invention is not concerned. The peculiar and dangerous nature of colloid smokeless powder sticks, the necessity for an economical, safe and sure method of detecting faulty sticks, the large attenuation of sound waves in passing through the sticks and formation of bubbles on the surface of the stick with consequent false indication of flaws and rejection of perfectly sound sticks, present problems which are not solvable by an adaptation of these teachings. The

3

use of ultrasonic waves broadly for these purposes is not claimed; but only in combination with the other procedures set forth and claimed.

The nature and purpose of this invention has been indicated in a general way, and there follows a more detailed description of the preferred embodiments thereof with reference to the accompanying drawings in which:

Figure 1 is a diagrammatic view of the apparatus utilized in carrying out the invention; Figure 2 is a diagrammatic view of the scanning device; Figure 3 is an end view of a colloided smokeless powder stick of cruciform cross section showing means for supporting the stick during the scanning operation; Figure 4 is an end view of a cruciform stick showing the arrangement of two pairs of transducers or piezoelectric crystal transmitters and receivers positioned adjacent one end of the stick; Figure 5 is a view similar to Figure 4 showing two additional pairs of transducers spaced from the first two pairs longitudinally of the stick; Figures 6 and 7 are similar views showing the arrangement of two additional pairs of transducers spaced longitudinally of the stick with respect to those shown in Figures 4 and 5; and Figure 8 is a graph showing in Case I the attenuation of the ultrasonic waves in passing from the transmitter, through the water and stick, to the receiver and in Case II the effect due to the detection of a flaw in the smokeless powder stick.

The successive steps of the method, as applied to a smokeless powder stick, are shown in Figure 1. Conveying means for moving the stick from point to point have been omitted for the sake of simplicity and clarity. Progressive movement may be accomplished by endless conveyor means. Preferably each stick is pushed through the scanning device by the next following stick and not directly by the conveying means.

The stick of smokeless powder 1 is first sprayed with a dilute solution of a wetting agent to insure subsequent wetting and prevent the formation of bubbles. The wetting agent is pumped from the tank 2 by the pump 3 and delivered by piping 4 to the sprays 5. The arrangement of the pump 3 and sprays 5 is such as to deliver a coarse, low pressure spray of liquid in a manner to thoroughly wet the entire surface of the stick. High pressures are to be avoided since they cause foaming with consequent loss of effectiveness of the spraying and increased likelihood of forming bubbles.

After the spraying operation the stick 1 is thoroughly wiped by the wipers 6. This may be satisfactorily accomplished by passing the stick through a plurality of spring pressed felt wipers so arranged that excess wetting agent is removed and the remaining liquid uniformly and evenly distributed over all surfaces of the stick. The excess treating agent drains back to the tank 2 and is again available for recycling through the sprays 5. In addition to conserving the treating liquid and spreading it on the stick the wipers 6 further insure that excess wetting agent is not carried into the ensuing water bath thereby increasing the concentration of this material in the water to an undesirable point. Although felt wipers have been indicated it will be realized that other suitable types of wipers such as brushes, and other materials such as canvas and rubber may be used. In some cases a water spray may be substituted for the wipers with advantageous results. Such modifications are contemplated as

4

within the scope of this invention as long as the desired results are attained thereby.

The stick is next immersed in a water bath 7 contained in tank 8. It has been found highly desirable to apply an underwater jet to the stick to remove any persistent air bubbles and to rinse off any adhering film remaining after the wetting agent application, wiping, etc. This is essential, since it has been found that a bubble passing through the transducer field registers as a flaw, and that a film on the stick causes an extra interface which results in a supersonic wave attenuation that registers as an erratic aberration of the ink line on the recorder. Either of these effects would cause the rejection of a stick that might be flawless.

This rinsing is accomplished by a plurality of underwater jets 9 so arranged as to direct water on all surfaces thereof. Here again high pressures are to be avoided and a suitable low pressure used, to effect a sufficient flow of water along the stick to insure thorough rinsing and the dislodgement of any bubbles which may have persisted thereon. In some cases pretreatment with a wetting agent followed by immersion in the water bath will effect the desired wetting of the stick and thus render the underwater spraying action unnecessary. However, in order to insure complete wetting of the stick and absence of bubbles at all times, it is preferred to utilize the jets 9 in connection with each stick tested.

Being thoroughly wet and free of adherent bubbles, the stick 1 is now ready for passage through the scanning device diagrammatically represented in Figure 1 by the transducers or piezo electric crystal transmitters and receivers 10 and 11 and associated electronic apparatus 12. This device is shown more particularly in Figure 2, wherein high frequency electrical oscillations are produced by the electrical impulse generator and controller 14 and converted into ultrasonic waves, directionally beamed through the stick being tested, by the piezo electric crystals of the transmitting transducers 16. After passing through the stick the waves are picked up by the piezo electrical crystals of the receiver transducers 17, amplified by the tuned amplifier 18, rectified and amplified by the rectifier and amplifier 19, and recorded by the pen recorder 20.

The electrical impulse generator and controller 14 may comprise any suitable mechanism which will produce high frequency electrical oscillations between about 300 kilocycles and 500 kilocycles per second, which can actuate the piezoelectric crystals of the transmitting transducers 16. Amplification may be provided, as required, to produce ultrasonic signals of requisite magnitude. Thus electronic tubes, such as the 6SJ7 for example, may be used with suitable amplification, to produce the desired oscillations. Equipment of this type is the Model BE201 noise generator manufactured by the Brush Development Company, Cleveland, Ohio. Preferably a Model BE302, made by the same company, and having a frequency of controlled randomness (frequency modulation) and carefully controlled stability in amplitude is used. In the BE201 model, the control of randomness is effected by screening out the marginal frequencies, while the BE302 unit's primary oscillator (400 kilocycles) has a secondary (200 cycle) oscillator and modulator, to produce a variation of the primary 400 kilocycles through a range of approximately 50 kilocycles.

The electrical oscillations so produced are then applied to the piezoelectric crystals of the trans-

5

mitting transducers 16 (Figure 2) for conversion into ultrasonic waves. Each of the transmitting transducers 16 comprises an assembly including a crystal, usually of Rochelle salt (potassium sodium tartrate) which has the property of expanding and contracting in response to a pulsating current applied to it. This rapid vibration of the transmitting crystal produces the high frequency ultrasonic waves which are used in this invention. The dimensions of the crystal are correlated with the frequency of alternations which, for that crystal, will give the best results as to flaw detection. Thus, for the size and shape of powder stick and the frequencies employed, crystals approximately  $\frac{1}{4}$  inch thick by  $\frac{3}{8}$  inch wide by  $1\frac{1}{2}$  inches or 1 inch long have been found satisfactory. It will be understood that the above dimensions are empirical, and that the other conditions of frequency of oscillation and of stick dimensions and figuration will require other crystal sizes and shapes. Each crystal is enclosed in a brass casing containing castor oil. The casing is provided with a rubber cap and electric cable connections to the electrical impulse generator.

Each of the receiving transducers 17 is a duplicate of the transmitter 16. Waves from the latter beat upon the crystal of the former and cause it to vibrate. This vibration sets up tiny pulsating currents which are in phase with the original pulsations of the impulse generator. These pulsating currents are amplified by the tuned amplifier 18 through the cable connections 21.

The transmitting and receiving transducers are each fixed in a holder and positioned so that their axes are co-linear, i. e., the faces of the crystals are parallel and opposite and corresponding edges are parallel. The faces of the crystals are further positioned parallel to the axis of the powder stick and at a distance apart approximately  $\frac{1}{2}$  inch greater than the diameter of the stick. The number of transducers required will depend upon the size and shape of the stick of smokeless powder being examined, the size and shape of the transducers and the number of passes required for complete scanning obtained by a plurality of passes. In the present invention it is preferred to utilize a plurality of transducers of suitable size to effect complete scanning in a single pass. In the case of cruciform sticks it has been found that six pairs are desirable. Four pairs will serve the four arms and two other pairs will be directed diagonally across the four crotches, thus completely covering the whole stick. Such an arrangement is shown in Figures 4, 5, 6 and 7. The pairs of transducers are spaced longitudinally along the stick in such manner that the ultrasonic waves passing from the transmitter to the receiver of one pair do not interfere with or adversely affect the waves passing between the transmitter and receiver of another pair. Thus, for example, the two pairs of transducers shown in Figure 4 may be located adjacent one end of the stick, those in Figure 5 adjacent the opposite end of the stick, and those in Figures 6 and 7 at intermediate points of the stick. Other arrangements may be utilized as long as complete scanning is attained and there is no adverse interference between the several bands of ultrasonic waves.

The tuned amplifier 18 may comprise any well known means for receiving the pulsating impulses from the transducer 17 (Figure 2) and selectively amplifying them until the voltage is high enough to operate a detector efficiently.

6

The use of a tuned amplifier increases the discrimination between signal and noise.

The output from the amplifier is rectified and amplified by a suitable rectifier and amplifier 19 in order to obtain a direct current voltage, the magnitude of which will be a function of the signal being received by the receiver transducers. A change from a standard set signal pattern indicates a flaw.

The direct current voltage so produced may then be applied directly to the pen recorder 20 to produce an inked chart representing the acoustical insertion loss of the sample. The recording apparatus may comprise a recording pen which may be essentially the needle of an undamped D'Arsonval type galvanometer, the pen graphing a picture of any current or voltage fluctuations due to flaws. The pen should have a very short period (about 0.02 sec.) in order to record the presence of very small flaws in the brief time they are in the ultrasonic field.

During passage through the field of ultrasonic waves it is important that the smokeless powder stick be firmly held against lateral or rotational movement. This is attained, in the case of sticks of cruciform shape, by the arrangement of rollers shown in Figure 3 wherein grain 40 is pressed downwardly on rollers 41 and 42 by spring pressed rollers 43 and 44. A series of such rollers lends support over the entire length of the stick. Other suitable arrangements or supporting means may be used for the cruciform and other types of smokeless powder stick as long as lateral and rotational movement are prevented.

The scanning operation, according to this invention, may be conducted to greatest advantage in a water bath since the comparatively high absorption of ultrasonic waves in air, as compared to water, results in high attenuation and makes it extremely difficult to pick up the waves and positively identify a flaw. Other liquids such as oil are too difficult to remove from the powder stick. Since the crystals of the transducers are comparatively unresponsive at temperatures below 70° F. it is desirable to maintain the temperature of the water bath above that point. However, temperatures within the range between 74 and 76° F. are to be avoided since the crystals are several times as sensitive in that range as immediately above or below and hence would adversely affect the accuracy of the results. It is preferred to heat the water bath initially by means of a steam pipe or similar device, to a temperature of approximately 80° F. and then to run in enough cold water to drop the temperature to 74° F. maximum, 70° F. minimum. This operation drives out most of the dissolved air and reduces the temperature of the water to a point where cooling will have a reduced effect on results. It will be understood that temperatures from 76° F. to 80° F., and preferably nearer 80° F., are permissible and may advantageously be used during certain periods of the year.

While ultrasonic waves of lower frequencies may be used, it has been found that high frequencies varying from about 300 kilocycles per second to about 500 kilocycles per second, give the best results. High frequency waves may be positively directed in straight lines through any selected portion of the grain and without the likelihood of stray waves bending around the grain as in the lower frequencies. A band of frequencies is preferable to a single frequency since the latter is likely to cause reflected

waves from surfaces such as the sides of the tank and the surface of the water bath to produce standing waves whose effect would be to nullify the sensitivity of the detection. The band of frequencies causes these reflected waves, in effect, to counteract each other so that standing waves are not established. The band of frequencies may desirably be from about 20 to 50 kilocycles wide and has been found to be most satisfactory when centered in the vicinity of 440 kilocycles. This is indicated by the data in the table below wherein the attenuation of ultrasonic waves of various frequencies in passing through a flaw-free section and a corresponding flaw-containing section of a stick of colloided smokeless powder is set forth. Thus, an attenuation of 24.5 db. was obtained in passing an ultrasonic wave of 440 kc. through a stick of smokeless powder. This value remained substantially constant as the stick was moved longitudinally through the path of the sound wave until the flaw was reached and an attenuation of 34.5 db. was obtained. The difference, being the attenuation due to the flaw, was 10 db. This value is the maximum attenuation for the flaw in question from any of the frequencies noted in this table.

Table

| Ultrasonic Wave Frequency (kc.) | Attenuation Through Grain of Colloided Smokeless Powder (db) |         |        |
|---------------------------------|--------------------------------------------------------------|---------|--------|
|                                 | No Flaws                                                     | At Flaw | Change |
| 50.....                         | 5                                                            | 7.5     | 2.5    |
| 75.....                         | 6                                                            | 9       | 3      |
| 100.....                        | 5.5                                                          | 10.5    | 5      |
| 140.....                        | 6                                                            | 11.25   | 5.25   |
| 200.....                        | 8                                                            | 13      | 5      |
| 260.....                        | 11.5                                                         | 18.5    | 7      |
| 335.....                        | 19                                                           | 28      | 9      |
| 440.....                        | 24.5                                                         | 34.5    | 10     |
| 535.....                        | 29                                                           | 24      | 4      |
| 800.....                        | 11                                                           | 14.5    | 3.5    |

In the scanning operation, the high frequency ultrasonic waves, passed through the powder stick, are reflected or otherwise interfered with by an obstruction in their path. This interference or attenuation is measured and its magnitude gives an indication of the size of a void or fissure such as an air blister, vacuum blister or other lack of continuity in the interior of a powder stick. The attenuation or power losses in the sound waves in passing from the transmitter through the water and the stick to the receiver are distributed as shown in Figure 8. Where there is no flaw, as in Case I, there is a very slight drop in power through the water between transducer and stick due to absorption; a large drop at the water-powder interface because of reflection and dispersion; a small, gradual drop through the powder stick due to absorption; a drop at the powder-water interface because of reflection; and a small drop through the water to the receiving transducer by absorption. This curve, Case I, establishes the reference line of the recorder. If a flaw is present, as in Case II, the power level drops for two reasons, i. e., dispersion as refraction and reflection at the fissure-powder interface and increased absorption by passage through the fissure. This drop, when compared with the reference line (Case I), indicates the location and magnitude of the flaw detected.

After the scanning operation the stick is removed from the water bath, washed with water and then air dried. The water washing apparatus

comprises a plurality of sprays 45 and a receiving tank 46. The air drying apparatus may comprise a plurality of air nozzles 47.

While the methods and apparatus of this invention are designed particularly for testing colloided smokeless powder grains of cruciform shape, they may equally well be applied to the testing of grains of other shapes as well as the testing of other materials having water repellent surfaces. Thus, for example, grains of cylindrical, rosette or other cross section may be tested by suitable modifications of the device which will be apparent to one skilled in the art. The presence of flaws in plastics, certain metals such as aluminum and similar materials may likewise be detected by the procedures of this invention.

Although it has been found that very satisfactory results are obtained by the use of from about 0.01% to 0.10% and preferably about 0.02% of a solution of the sodium salt of dioctyl succinate in water as the wetting agent, other materials of a similar nature which do not deteriorate or adversely affect the material being treated, may be used. Suitable materials of this nature are pine oil, soap, sulfonated castor oil, sulfonated fatty acids and triethanolamine fatty acid esters.

In some cases it may be desirable to move the ultrasonic wave zone while holding the stick stationary to accomplish scanning. This may readily be accomplished by obvious modifications of the apparatus described and claimed.

The transducer crystals have been described as constructed of Rochelle salt. However, other suitable piezo crystalline structures may be used. For some purposes, magnetostriction metallic rods are applicable.

The methods and apparatus of the present invention have made it possible to detect all flaws in smokeless powder grains with a sureness and speed not realized in devices hitherto known and utilized. Thus, they are superior to and have replaced X-rays in this type of application. These factors, together with the increased economy and safety of this method and apparatus, have resulted in great savings, an increased production of stick powder and the elimination of the hazards and inaccuracies occasioned by the use of faulty sticks.

What I claim and desire to protect by Letters Patent is:

1. A method of detecting flaws in a stick of smokeless powder comprising immersing the stick in a liquid medium, removing any bubbles, which may have formed, from the surface of the stick, creating frequency modulated ultrasonic waves of high frequency, passing said waves through a portion of the stick, moving the stick perpendicularly with respect to the path of said waves and at a uniform speed to insure passage of said waves through all portions of the stick, and registering the degree of attenuation of said waves in passing through the stick.
2. A method of detecting flaws in a stick of smokeless powder comprising immersing the stick in water, spraying the stick with an underwater spray to remove adherent bubbles, creating frequency modulated ultrasonic waves of high frequency, passing said waves through a portion of the stick, moving the stick perpendicularly with respect to the path of said waves and at a uniform speed to insure passage of said waves through all portions of the stick, and registering the degree of attenuation of said waves in passing through the stick.

3. A method of detecting flaws in a grain of smokeless powder comprising treating the stick with a wetting agent, removing the excess wetting agent, immersing the stick in water, spraying the stick with an underwater spray to insure thorough wetting and absence of bubbles, progressively subjecting all portions of the stick to frequency modulated high frequency ultrasonic waves, picking up said waves on the opposite side of the stick after passage therethrough, and recording the degree of attenuation of said waves in passing through the stick.

4. A method of detecting flaws in a stick of smokeless powder comprising treating the stick with a wetting agent, immersing the stick in water, progressively subjecting all portions of the stick to frequency modulated ultrasonic waves of a frequency within the range of about 300 kilocycles to about 500 kilocycles per second, picking up said waves on the opposite side of the stick after passage therethrough, and recording the changes in attenuation of said waves in passing through successive portions of the stick.

5. A method of detecting flaws in a stick of smokeless powder comprising immersing the stick in water, removing adherent bubbles from the surface of the stick, creating frequency modulated ultrasonic waves of high frequency, passing said waves through a portion of the stick from a point in the water adjacent the stick, picking up said waves at a point in the water adjacent the opposite side of the stick and after passage therethrough, continuously moving the stick longitudinally, at a uniform speed through the field of said waves in such manner that the whole stick is progressively exposed to said waves, holding the stick against rotational and lateral movement to prevent misleading attenuation of said waves, and recording the differences in attenuation of said waves in passing through successive portions of the stick.

6. A method of detecting flaws in a stick of smokeless powder comprising treating the stick with a wetting agent, immersing the stick in water, removing adherent bubbles from the surface of the stick, creating frequency modulated ultrasonic waves of high frequency, passing said

waves through a portion of the stick from a point in the water adjacent the stick, picking up said waves at a point in the water adjacent the opposite side of the stick and after passage therethrough, continuously moving the stick longitudinally, at a uniform speed, through the field of said waves in such manner that the whole stick is progressively exposed to said waves, holding the stick against rotational and lateral movement to prevent misleading attenuation of said waves, and recording the differences in attenuation of said waves in passing through successive portions of the stick.

7. A method of detecting flaws in a stick of smokeless powder comprising treating the stick with a wetting agent, removing excess wetting agent to prevent contamination of the water in the ensuing water treatment, immersing the stick in water, removing adherent bubbles from the surface of the stick, creating frequency modulated ultrasonic waves of high frequency, passing said waves through a portion of the stick from a point in the water adjacent the stick, picking up said waves at a point in the water adjacent the opposite side of the stick and after passage therethrough, continuously moving the stick longitudinally, at a uniform speed, through the field of said waves in such manner that the whole stick is progressively exposed to said waves, holding the stick against rotational and lateral movement to prevent misleading attenuation of said waves, and recording the differences in attenuation of said waves in passing through successive portions of the stick.

WILLIAM E. PIPER.

#### REFERENCES CITED

The following references are of record in the file of this patent:

#### UNITED STATES PATENTS

| Number    | Name            | Date          |
|-----------|-----------------|---------------|
| 759,622   | Lake            | May 10, 1904  |
| 2,142,024 | Hall            | Dec. 27, 1938 |
| 2,270,922 | Beckmann et al. | Jan. 27, 1941 |
| 2,378,237 | Morris          | June 12, 1945 |
| 2,483,821 | Firestone       | Oct. 4, 1949  |