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Non-contact Sonic Infrared Imaging System for Nondestructive Evaluation of Materials

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ABSTRACT

The invention describes the development of a high resolution non-contact acoustic imaging instrument that can be utilized for nondestructive evaluation of materials and components. A high amplitude acoustic wave is incident on one face of the material under test. The acoustic waves propagating through the material are detected by an optical probe on the opposite face. The sample is raster scanned in two mutually perpendicular directions and the amplitude detected by an optical probe is utilized to develop an acoustic image. The non-contact nature of excitation and detection makes this instrument unique for high resolution acoustic imaging and can be utilized for nondestructive evaluation of varieties of materials and components [polymers, composites, metals and ceramics]. One of the important industrial applications will be in the evaluation of electronic and micro-electronic components with out immersion in water. In the current configuration and operation the instrument has a spatial resolution of a few hundred microns. Attempts to improve the resolution are underway and would be completed in a couple of months.

DETAILED DESCRIPTION

INTENT

The purpose of the invention is to develop a high resolution non-contact acoustic imaging system for nondestructive evaluation and testing of materials and components.

BACKGROUND

During the last decades, several nondestructive techniques, based on acoustic wave propagation, have been developed for evaluation and testing of materials and components [1, 2]. The ability of acoustic waves to penetrate, into the interior of the material, has been utilized to obtain critical information, about the life limiting defects in materials as well as components [3, 4]. More over, acoustic waves propagate through different kinds of materials; thus it has found applications in metals, ceramics, and composites etc. Most often in acoustic testing, the acoustic waves are excited in the material by placing an ultrasonic transducer, in direct contact. A coupling medium like water, oil, grease or thin solid material is used between the transducer and the material. As the acoustic waves propagate through the material, defects along the path, reflect/scatter the acoustic waves. The reflected/scattered signal are detected using the same ultrasonic transducer [pulse-echo] or by placing another transducer in contact with the material [thru transmission]. While this technique allows, examination of individual locations, it is extremely time consuming to obtain an image of larger structures. More over, the spatial resolution is determined by the diameter of the transducer. In order to enhance the resolution and ease the restriction on scanning, focused acoustic beam techniques in presence of water were developed. These techniques are known C-scan, C-SAM, and Scanning Acoustic Microscopy [5, 6]. In these methods, the acoustic waves are focused on or in the interior of the material under test in presence of water. The reflected/transmitted signals are detected by the same lens transducer, gated, amplified, digitized and stored in a computer. The transducer or the sample is raster scanned and an acoustic image is constructed using the stored amplitude data. The spatial resolution depends on the acoustic wavelength in water. Typically at 100 MHz the resolution is about 15 μm. Utilizing frequencies of the order of 2 GHz resolution comparable to optical microscope (0.5 μm) have been developed. While higher frequencies provide higher spatial resolution, the penetration depth dramatically decreases, minimizing the advantage of in-depth evaluation of the material. Although, acoustic techniques are routinely used for nondestructive evaluation and testing, the material has to be immersed in a fluid (often water).

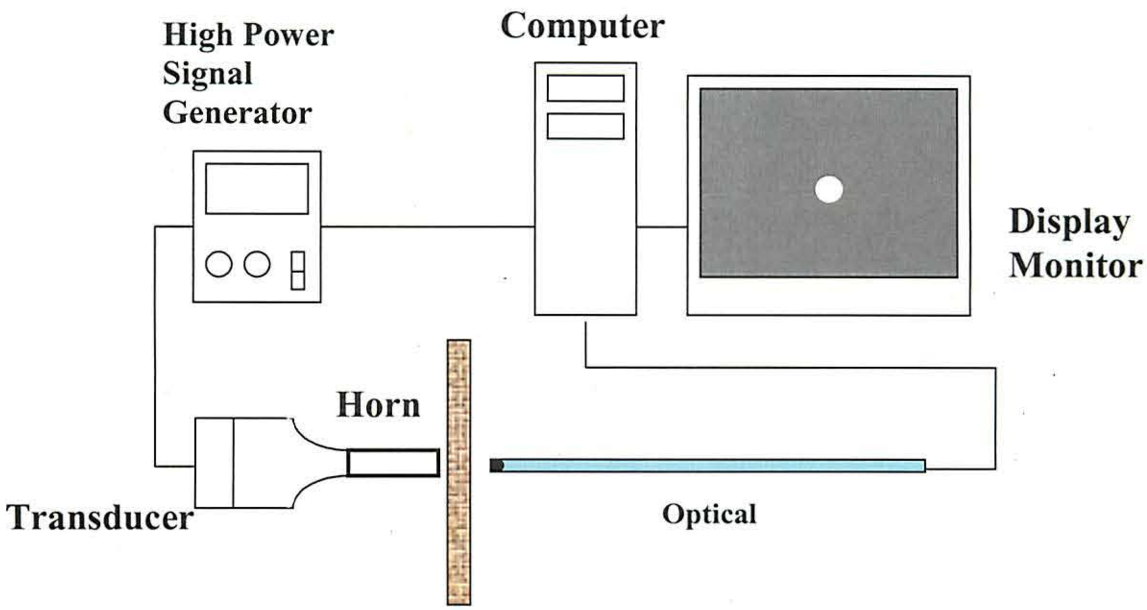
To overcome the water contact problem, specialized air coupled ultrasonic transducers (both un-focused and focused) have been developed [7, 8, 9].

These transducers operate in air at frequencies in the range of a few hundred KHz to about 5 MHz. Acoustic waves generated by these transducers propagate through air are incident on the sample surface. Some amount of the acoustic energy is reflected, while a small amount will pass through the material. The transmitted signal is detected by another air coupled transducer. There is significant loss of acoustic energy at the sample air interface, because of huge acoustic impedance mismatch between the solid material and air. Thus, the received signal requires enormous amount of amplification. It also requires significant signal processing to before detecting the acoustic signal that travels through the material. Although, this is a significant improvement, the spatial resolution is limited by the diameter of the transducer and operating frequencies. In fact the receiving transducer has the same size as the transmitting transducer. It is well known that the amplitude of the received signal is directly proportional to the diameter of the transducer. Thus larger diameter transducers are often used in the experiments. The air coupled ultrasonic imaging has found several applications both in material evaluation and testing as well as in biomedical applications because it can be performed in air.

Another method of complete non-contact acoustic imaging is with the help of laser generated acoustic waves and laser based detection systems. In these methods a high intensity laser periodically impacts, the surface of the sample. Due to thermo-elastic conversion, an acoustic wave is generated in the material. The propagating acoustic waves cause surface displacements and are detected by a laser interferometer at any other location. By scanning the excitation laser and the detecting interferometer an acoustic image is developed. The laser ultrasonic methods have high resolution and are completely non contact in nature. One of the major problems with the methodology is the need for exotic high amplitude pulsed lasers for generation of acoustic waves. The possibility of surface damage caused by the high power lasers due to ablation is a major limitation of this technique.

DESCRIPTION OF THE INVENTION

Figure 1 shows the block diagram of the non-contact near field high resolution acoustic imaging system. The basic components of the instrument are high amplitude acoustic wave generator, a fiber optic detector, amplifier and computer. The acoustic wave generator consists of a stack of piezo-electric transducers to generate 20 KHz acoustic waves. The principle of stacking a series of transducers is to obtain significant high amplitude acoustic waves. The acoustic amplitude is further amplified with the help of a mechanical amplifier; an acoustic horn. At the end of the acoustic horn, the amplitude of the acoustic waves can develop up to several hundred microns. The sample to be tested is placed at a small distance from the end of the acoustic horn. The high amplitude acoustic waves impinge on the sample. The sample reflects part of the energy and it also transmits some of the energy. The transmitted energy can be optimized by adjusting the distance between the sample and the horn. Acoustic waves propagating through the material produce longitudinal displacements on the opposite side of the sample. These surface displacements are normal to the



plane of the sample surface and are detected using a fiber optic cable placed at an appropriate distance from the surface of the sample. The fiber optical detector consists of a set of fibers, to illuminate the surface of the material, and the reflected light is detected by another set of optical fibers. The detected signal is carried to a photo-detector for measurement. The amplitude of the reflected light is proportional to the surface displacement. The amplitude of the signal from the optical fiber is further amplified, digitized and stored in a computer. The diameter of the entire optical fiber detector is approximately a few hundred microns. While keeping the acoustic horn and the fiber optic detector at a fixed position the sample is raster scanned. The amplitude data at each location is stored in the computer and an acoustic image is developed.

The spatial resolution of the instrument depends on the diameter of the optical probe that detects and measures the acoustic amplitude and not on the frequency of the acoustic wave. The wavelength of the acoustic waves in most materials at 20 KHz is several orders of magnitude larger than the diameter of the detecting probe. The wavelength of the acoustic wave in air is also extremely large compared to the diameter of the optical probe and the distance between the sample and the detecting probe. These conditions make the instrument to operate as near field imaging system

[10]. Currently, the instrument has been developed using commercially available off the shelf equipment and software. The high amplitude acoustic transducer is a (Branson) ultrasonic welding unit. The optical detector is a commercially available vibration sensor. The spatial resolution of the instrument in the current configuration is in the range of few hundred microns which is equal to the diameter of the optical fiber sensor. The distance between the specimen and the optical detector is a few millimeters. The optical fiber detector can be replaced by a commercially available laser interferometer [Ploytec Vibrometer] to increase the spatial resolution to a few microns and specimen - detector to at least to a meter. The operating distance between the specimen and the acoustic excitation source is in the range of 1-2 millimeters. This may be extended through optimization up to several millimeters.

APPLICABILITY OF THE INVENTION

Although the instrument can be used in general for non-contact nondestructive evaluation of materials and components, the major impact is expected to be in the area of polymers, sheet metals and components. Another important of the application is in the electronic and micro-electronic industry where immersion of components in water should be avoided.

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ROLE OF THE INVENTORS

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   Development of the concept, instrument optimization and testing
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