HIGH VOLTAGE ULTRASONIC PULSER

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Abstract - Ultrasonic technique uses transmission of high-frequency sound waves into a material to detect flaws or to find out changes in different material properties.1-15MHz frequency is generally used for specialized application and frequencies upto 100-150 MHz are also necessary. Mostly piezoelectric transducer is used in such application. Ultrasonic waves are created by using excitation of piezoelectric transducer with high voltage and narrow pulse.The Pulser/Receiver constitutes the most important part of an Ultrasonic Flaw Detector or an Ultrasonic Imaging System used for inspection of materials.The ultrasonic properties of the material and resolution requirements govern the choice of the frequency o f ultrasound that can be optimally used. The Pulser/Receiver in turn decides the efficiency of excitation of the transducer and the overall signal to noise ratio of the system for best sensitivity and resolution.This system is used for ultrasonic inspection of zircaloy-2 pressue tubes for pressurised heavy water reactors and for end fittings of PHWRs.

Keywords - Non destructive Testig , Piezoelectric transducer ,Pulser- receiver.

I. INTRODUCTION

Ultrasonic flaw detector which is mostly used instrument for non destructive techniques of various kinds of materials.The pulse generator is the most critical part in all ultrasonic systems. There are different kinds of techniques used for exciting ultrasonic transducer.Ultrasonic testing is a very versatile inspection method and inspections can be accomplished in a number of different ways. Pulse echo is the most commonly used ultrasonic testing technique , in this technique sound is introduced into a test object and echoes (reflection) are returned to a receiver from internal flaws or from the object’s geometrical surfaces.The Ultrasonic based Non-Destructive Testing (NDT) is a widely used and well-established technique for inspecting, testing, or evaluating of materials, components or assemblies with features of non-invasiveness, low-cost and real-time capability.

There are two different methods commonly used for exciting ultrasonic transducers in the pulse echo mode. The first involves the generation of a medium voltage, pulsed, radio frequency sinusoid using a gated oscillator, and the second involves the generation of a high voltage spike by a sudden discharge of a capacitor charged to several hundreds of volts. Comparatively, the first method is the more complex and the maximum pulsed voltage is typically limited to tens of volts. On the other hand, the second method, referred to as shock excitation, has the virtue of being simple, being easier to build and producing a maximum pulsed voltage capability of many hundreds of volts. A well-known shock excitation curcuit that is still in common use constists of a capacitor initially charged to a high voltage which is suddenly applied to a transducer using a MOSFET as a switch. Higher value voltage pulses are required for adequate penetration.This constraint implies either higher breakdown voltage capability of the switching element or circuit techniques that employ series connected elements. Since MOSFET are able to withstand higher voltages before breakdown occurs than avalanche transistors, they are more readily employed for applications involving highly attenuative materials.[14]. Higher frequency (>15MHz) ultrasound imaging systems have provided better spatial resolution than lower frequency systems.

The Pulser/Receiver constitutes the most vital part of an Ultrasonic Flaw Detector or an Ultrasonic Imaging System used for inspection of materials. The ultrasonic properties of the material and resolution requirements govern the choice o f the frequency of ultrasound that can be optimally used. The Pulser/Receiver in turn decides the efficiency of excitation of the transducer and the overall signal to noise ratio of the system for best sensitivity and resolution. A variety of pulsers are used in the ultrasonic instruments employed for materials inspection.

There are four different types of ultrasonic generators are used for generation of ultrasound frequency: spike pulser, bipolar tone burst pulser, square wave pulser ,and step pulser.lets see them in details.

1. Spike Pulser:

Spike Pulsers are perhaps the most commonly used electronic circuits for exciting piezo-electric transducers.we will discuss this in section II

2. Square Wave Pulser:

The rapid development of new fast switching semiconductor devices has led to the proliferation of square wave pulsers in ultrasonic instruments. The basic disadvantages of square wave pulsers (high component count and appreciable power consumption) are offset by important operational advantages. The use of square wave pulser, increases the ability of the user to control and stabilize important test parameters, including the harmonic content (spectrum) of the transmitted ultrasonic pulses. Also, the use of square wave pulse may result in higher pulse amplitudes and thus provides higher sensitivity needed for detection of smaller discontinuities. High power MOSFETs are commonly used in square wave pulsers intended to drive transducers between some frequencies,. Some very fast MOSFETs enable generation of very short pulses of the order of few nanoseconds with an amplitude of around very large volts. They can handle pulse currents of some Ampere and higher. Consequently, square wave pulsers are well suited for driving large size, low frequency transducers which frequently exhibit high capacitances. Initially the square wave pulser operates in a manner similar to that of spike pulser.

The time duration "T" of the square wave pulse must be carefully adjusted to produce a positive interference between the ultrasonic signals excited by the positive going and negative going transitions of the transducer. If the pulse is too long, then a distorted ultrasonic waveform is observed. If the pulse is too short, then the ultrasonic pulse amplitude is significantly smaller than that achieved with an equivalent spike pulser. In practice, the pulse duration is adjusted precisely, by the operator using front panel controls. A propedy tuned square wave pulser can generate twice as much echo signal amplitude as a spike pulse charged to the same high voltage. Even larger improvements in signal strength are possible when a suitable impedance-matching device is employed between the transducer and the pulser. The theoretical and practical advantages of square wave pulsers are now well known. Except for specialized applications, such as thickness gages and very high-resolution discontinuity detectors, the use of square wave pulser leads to a better performance as compared to a spike pulser. To optimize the performance of a superior square wave pulser, the damping resistor RD and pulse duration must be adjusted independently for each transducer. In spike pulser, however, only the value of damping resistor RD is operator adjustable.[2]

3.Tone Burst Pulser:

Tone burst pulser operation is essentially an extension of a square wave pulser operation and can be achieved by repetitively operating the square wave pulser . The main advantage of operating the square wave pulser in the tone burst mode is that it allows the operator to maximize the energy of the transmitted signal at a specific frequency. Tone burst operation can also be achieved when a spike pulser is used to drive an inductively tuned transducers. However, in this case, frequency control can be realized by altering the voltage of the tuning inductor. Tone burst pulsers are often designed for compatibility with impedance matching networks required to maximize the output of unconventional transducers: Electromagnetic Acoustic transducers, air coupled transducers, dry coupled and roller probes. Pulsers capable of generating more volt tone bursts at frequencies of several MHz are available. Tone burst excitation is often used in special instruments, including acoustic microscopes, where frequencies of several GHz have been demonstrated. Also, tone burst signals are used in many ultrasonic interferometers for material velocity measurements.

4. Step Pulsers:

The excitation of ultrasonic transducers with step pulses requires circuits that are topologically more complex than those discussed earlier. First the switchl is closed to allow the transducer to charge to a high voltage. Next Switch 1 is restored to the open position and switch Switch2 causes the transducer voltage to rapidly decay to zero. This rapid transition causes the generation of the unipolar ultrasonic waveform. In the case of a broadband, thin film, ferroelectric polymer transducer, the transducer output voltage is more compact than the bipolar pulse produced by a spike pulser. In this case, an external damping resistor is not required because a transducer with high internal damping is used.[2]

II. SYSTEM DESCRIPTION

A variety of pulsers are used in the ultrasonic instruments employed for materials inspection..The pulser receiver unit has been primarily designed for excitation of the transducer that is used for inspection of SSxxx billets, which are in turn used as the base material for fabrication of end fittings for coolant channels of Pressurised Heavy Water Nuclear Reactors (PHWRs). The design of the pulser is based upon very fast MOSFETs, configured as electronic switches. The pulser is operated with a linear bipolar H.V. supply. Fig.1.shows Block diagram of ultrasonic high voltage pulser which consist of HV ultrasonic pulser, ultrasonic transducer, metallic object for inspection, microcontroller, pc, amplifier, filter, DSO (Digital Storage Oscilloscope) and digitizer system.

The high voltage pulse generator (pulser) is the critical part of all ultrasonic imaging system. The GUI based application in the host computer (PC) is generally written in languages like C, Visual C++, Visual C#, VB, Java etc. USB Controller generates pulses with desired pulse width and pulse repetition frequency (PRF). High voltage pulser board also has a provision of onboard pulse generation using low voltage timing control circuit. The high voltage pulser generates high voltage pulses to excite an ultrasonic transducer through discharge capacitor. Ultrasonic transducer converts pulse electric energy into acoustic waves. The ultrasonic transducer is based on a piezoelectric disc, which resonates when excited by the high-voltage spike pulse. These vibrations are transferred into the test piece. The ultrasonic wave propagates through the test piece and reflected back to the transducer.

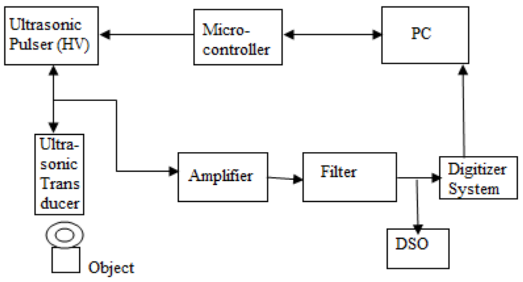

Fig.1. Block diagram of ultrasonic high voltage pulser

Different applications requires different pulse characteristics like B-mode imaging requires short pulses with wide bandwidth to achieve good axial resolution, Doppler imaging requires multiple pulses (tone-burst) to acquire flow information. Bipolar pulses can be used for high frequency ultrasonic applications and Doppler applications. The piezoelectric material in the receiving transducer is induced to vibrate by the received reflected ultrasonic wave and consequently generates an electrical signal. The signal is then amplified, filtered and digitized, and finally visualized on a digital oscilloscope or a computer screen. Some publication are available that are offering different pulser topologies for high voltage pulse generation for various application .

The ultrasonic pulser/receiver constitutes the most vital building block of an ultrasonic flaw detector or an Ultrasonic Imaging System used for inspection of materials. The pulser generates high volt excitation signal suitable for pulsed ultrasonic transducer.Overall signal to noise ratio of the system i.e.amplification of the signal is enhanced using high gain and high bandwidth receiver.The design of ultrasonic pulser is based upon very high speed and High power RF MOSFETs,configured as an electronic switch.

Ultrasonic Pulser is composed of four components: Power supply which supplies electrical energy, Low voltage pulse generator which provides various types of pulses, MOSFET Driver which drives the power MOSFET,and the High Voltage RF MOSFET which is used to generate the high voltage spike signal for excitation of ultrasonic transducer.

Use of Lead-zirconate-titanate or bismuth titanate type Piezo electric transducers are most common in such applications.Ultrasonic waves are generated when a high voltage, narrow pulse,excites the Piezo electric transducer.

1. Piezo electric transducer

Transducers used for ultrasonic testing incorporate a thin plate of a piezo-electric material to convert electrical energy, typically stored in a capacitor, into an ultrasonic signal. In most of the flaw detection and thickness gauging applications, it is advantageous to generate a compact ultrasonic waveform. This is best achieved by exciting the transducer with a short, unipolar voltage pulse whose rise time is shorter than the time required for an ultrasonic pulse to move through the piezo-electric plate.[2]

Use of Piezo-electric transducers is most common in all required applications.Ultrasound is generated when a high voltage, narrow pulse, excites a piezo-electric transducer. A close physical contact with the transducer enables coupling of ultrasonic energy into the desired material/object. Any acoustic discontinuity within the material will result in a change in the acoustic impedance and consequently the incident ultrasonic wave will be partially reflected back from such a location. The receiver transducer will pick up the reflected ultrasound and convert it back into an electrical signal.The intensity of the reflected waves depends upon the geometry and orientation of the discontinuity.Accordingly, the received echo signal displayed on an oscilloscope, can give a fair idea about the presence of defects if any in the object under testing.[2]

Fig. 2 shows a block diagram for a piezoelectric ultrasonic transmitter, including the excitation electronics, electrical tuning/damping networks at the electrical terminals of the transducer, the broadband piezoelectric transducer and the irradiated medium. Fig. 5 shows a more detailed configuration for the high-voltage section, and Fig. 7 a simplified version for the spike generation circuits which will be used to simulate the response of the high-voltage driving.

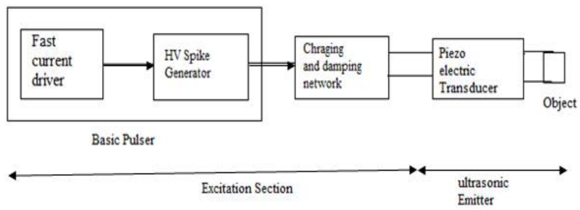

Fig. 2. Block diagram for a piezoelectric ultrasonic transmitter.

Classical analysis of the broadband response of piezoelectric transducers rely on the use of three-port matrix or circuit models, such as Mason, that provide an impulse response to be convolved with an ideal driving waveform (assuming electrical sources with linear and resistive characteristics). Nevertheless, efficient pulsers for NDT applications are frequently based on the spike excitation of piezoelectric transducers. This type of pulsers usually includes a power switching device (e.g. SCR or MOS-FET) and some rectifier components.The pulse waveform that actually arrives at the piezoelectric transducer electrodes, in the real highvoltage NDT context, is the result of different linear and non-linear interactions among the power switching, a capacitive discharge (including selective damping and tuning components) and the complex input impedance of the piezoelectric transducer under real loading conditions.[13]

2. Gate MOSFET Driver and MOSFET

This is the most important stage of the pulser.This stage must supply the electrical pulse of the desired voltage to the ultrasonic transducer.The general pulser contains one switch to produce the leading edge of high voltage pulse. The trailing edge of the high voltage pulse is produced by the register pull-up network.Normally the value of R which is connected between high voltage DC supply +HV and drain of the power MOSFET, should be low with the purpose of getting fast trailing edge response while charging the capacitor.One active element is responsible for leading edge.

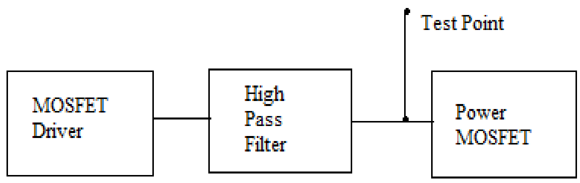

Fig.3. Interface between MOSFET Driver and Power MOSFET

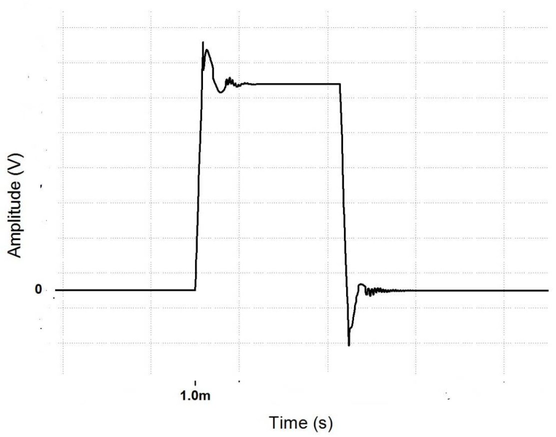

Fig.4. MOSFET gate input pulse from the Driver

Fig.3.shows interface between MOSFET driver and Power MOSFET. In-built pulse signal has been applied to the gate driver with specific pulse width, rise time, fall time, rise voltage and pulse delay. The waveforms at the gate of the power MOSFET is shown in Fig.4.The positive-going corner ring is from the inductance in the VCC supply path, while the negative-going corner ring is from inductance in the ground return path to the supply. The amount of ringing is primarily a function of how much current is present and the amount of loading. If the gate of MOSFET has higher capacitive input load then, pulse ringing effect can be reduced.

Charging capacitor effect on output of the spike pulser: So that the Capacitor C_C gradually charges up to the supply voltage (+HV). During the charging process there will be a small voltage across the load, which falls to zero as the capacitor charges up.

When positive edge pulse is applied to the MOSFET, it will suddenly on and the charge on the capacitor discharges and it will then decay exponentially. The output rise time and fall time at drain terminal depends on the drain capcitor value and load resisor value. Simulated rise time of the drain voltgae is specific ns(nano second) during capcior charging peroid and fall time is also specific ns(nano second) during capcitor rising period.

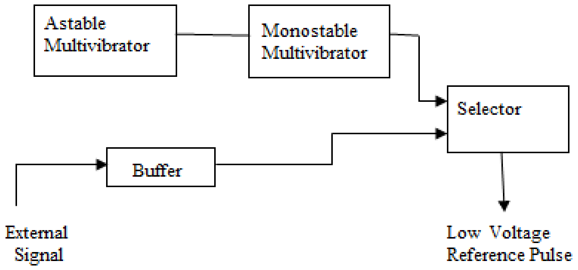

Fig.5. low voltage section of pulser

Fig.5. shows low voltage section of pulser.The storage time is decresed as value of capactor is changed from certain nanofarad.So we can get a sudden trailing edge during charging of external capacitor.But disadvantage is that peak overshoot is incresed which can cause oscillations during exciation of the ultrasonic transducer. so there is a trade off between peak overshoot and storage time of charging capacitor. The other solution is to the reduce drain resistance R_C. It also cause fast trailing edge response but it produce large power drop when MOSFET is on as current is high due to low resistance. Then the solution is to use short pulse for reduction of power.

3. Amplifier

The Amplifier board provides an additional gain. The gain can be set in steps of some dB giving the operator adequate flexibility for data collection. The amplified signal is buffered and routed to the Digitizer board for digitization and storage. In some applications, rectified echo signals are preferred over the RF echoes.

4. Digitizer:

The Digitizer board is the most crucial unit in this system. It provides user selectable sampling rates of 100, 50, 25 and 12.5 MSPS to ensure flexibility and optimal data acquisition.High sampling rate allows use of high frequency transducers that are necessary for improved resolution.The flash encoder samples the RF (i.e. the non-rectified) echo signals derived from the amplifier board to preserve the phase information. All these facilities allow the operator to acquire data in an uncompromising manner. The trigger signal (used on the Pulser/Receiver board) is generated by the digitizer board and the same is validated by a sub multiple of the sampling clock.This ensures perfect synchronization.

5. Modes of operation:

Following modes of operation are supported:

***(*i) Pulse-Echo (PE) mode :** In this mode, a single transducer acts both as the transmitter and receiver of ultrasound. This mode is the most widely used type.

(ii) Transmit-Receive (T/R) mode *:* In this mode, two separate transducers are used so that one acts as the transmitter and the other as the receiver.

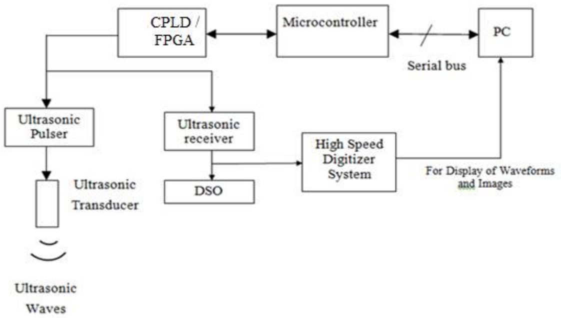

Fig.6 .block diagram of ultrasonic spike pulser by using CPLD? FPGA

Ultrasonic Flaw Detector, which is a very widely used instrument for NDT of various types of materials, essentially works on the basic principle of Pulseecho (PE) operation. In PE mode of excitation, basically the same transducer works as a transmitter of ultrasound and also as the receiver of the reflected ultrasonic waves received from discontinuities within the material under testing. In the Transmit-Receive (T-R) or Tandem technique of excitation, typically used for inspection of metallic plates etc., one transducer operates in transmit mode and the other transducer will have to be placed either on the opposite side of the plate along the line of sight of the transmitter or both transmitting and receiving transducers can be placed in an angular manner. In its simplest form the Flaw Detector consists of electronic circuits for generation and reception of ultrasound and a CRT/LCD with associated electronics for display of A-scan waveforms. Provisions are made so that the operator can set the relevant parameters in an optimum way for obtaining a clear and unambiguous display of echo signals. Such parameters include energy and damping controls, gain/sensitivity, band-pass filters, suppression (of spurious or noise signals), and time delays. User adjustable cursors may be provided for measurement of depths of defects, thickness measurement and measuring the amplitudes of defect echoes.[2].

Fig.6 shows block diagram of ultrasonic spike pulser by using CPLD/FPGA. The negative spike can be generated by using CPLD (Complex Programmable Logic Device) or FPGA(Field Programmable Gate Araay),but the constructuion becomes more hard than using controller but it gives better performance.

III. IMPLEMENTATION

The spice models for the different components in the design were imported into spice, and the circuit was simulated. A comparison between the spice prediction and a measured pulse response is shown in Fig. 12. The actual response has a slightly slower rise time, but the agreement is otherwise excellent. Experimental results are discussed further.

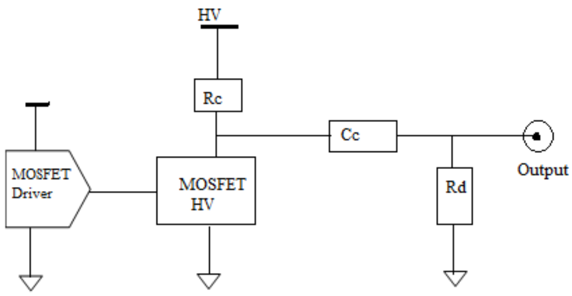

Fig.7. High voltage section of the spike pulser

An important component of every ultrasound system is the high voltage pulse generator used to excite the transducers. Designing a suitable pulse generator can be challenging and expensive, particularly for imaging systems operating above 20 MHz. Recently, high speed power MOSFETs have become available at a reasonable cost.By exploiting the large current-carrying capacity and fast-switching speed of these devices, a very simple and high-performance pulse generator can be built.

The performance of the pulse generator depends on the quality of power-supply bypass capacitors Standard capacitors provide sufficient filtering for the low-voltage supplies; however, the high-voltage supply is more sensitive due to potential ringing immediately following large pulses. The highvoltage supply capacitors used in this prototype are metalized capacitors. Two of these capacitors in parallel virtually eliminate ringing and produce extremely fast, smooth current discharges. The quality of the coupling capacitor situated before the gate of the output MOSFET also can affect the performance of the pulser significantly.

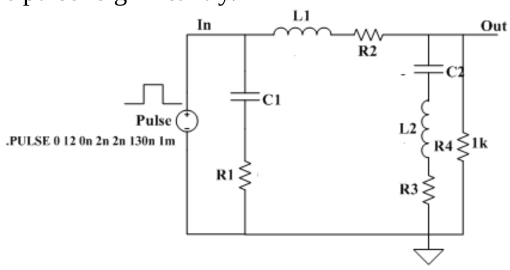

Fig.8 MOSFET Driver Spice model used for simulation

Here, the charging capacitor Cc is charged to a high voltage "+HV" through the charging resistor Rc and the damping resistor RD .The charging capacitor is charged to the full value (+HV) in a few microseconds.Thus, pulse repetition frequencies upto few KHz can be easily obtained. For the purpose of excitation, the switch S is rapidly closed for a short time interval. The closure of S. causes the voltage of the fully charged capacitor Cc to appear across the terminals of the transducer. This abrupt voltage change causes the piezo-electric material of the transducer to respond by emitting an ultrasonic wave. The exciting voltage then rapidly decays because of the damping resistor Ro,connected in parallel with the transducer.This value of Rd can be adjusted by the user to accommodate different transducer impedances. Proper adjustment of RD is important because, it directly determines transducer ringing time and the resulting near surface and axial resolution. Since the acoustic pressure at the front face of the transducer is directly proportional the time derivative of the applied voltage d (HV) / dt, it is important to minimize the rise time of the applied pulse. The rise time is primarily affected by the speed at which the switch S can be fully closed and by the presence of parasitic inductances in series with the capacitor, switch and transducer. Ultrasonic transducers are typically connected to the pulse with a length of co-axial cable . Therefore, the total capacitance of several meters of cable can be easily equal or exceed the capacitance of many transducers. In such cases, a major portion of the pulse energy can be shunted away from the transducer.The efficiency of the excitation can also be degraded by the series inductances and other parasitic impedances. Series inductances tend to increase rise times and prevent the high frequency portion of the pulse energy from reaching the transducer. These effects may severely affect the ability of a spike pulse to efficiently excite thin film transducers.[2]

Fig.9 shows Simulated Pulser output signal (voltage vs time) using LT Spice Fig. 10.shows Output pulses from the pulser. (a) The spice simulation of a 300 V output pulse driving a 50 Ω load. (b) Experimental 300 V output pulse of equivalent duration, driving a 50 Ω load.

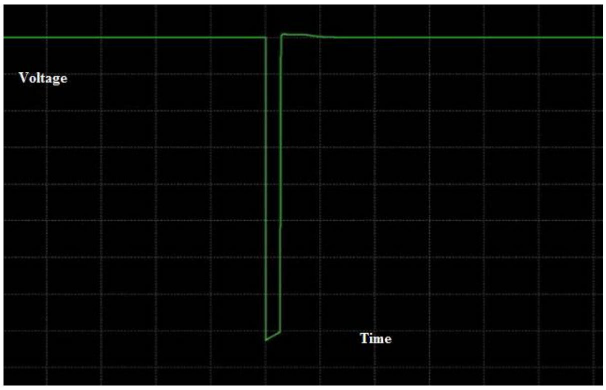

Fig.9 Simulated Pulser output signal on LT Spice simulator

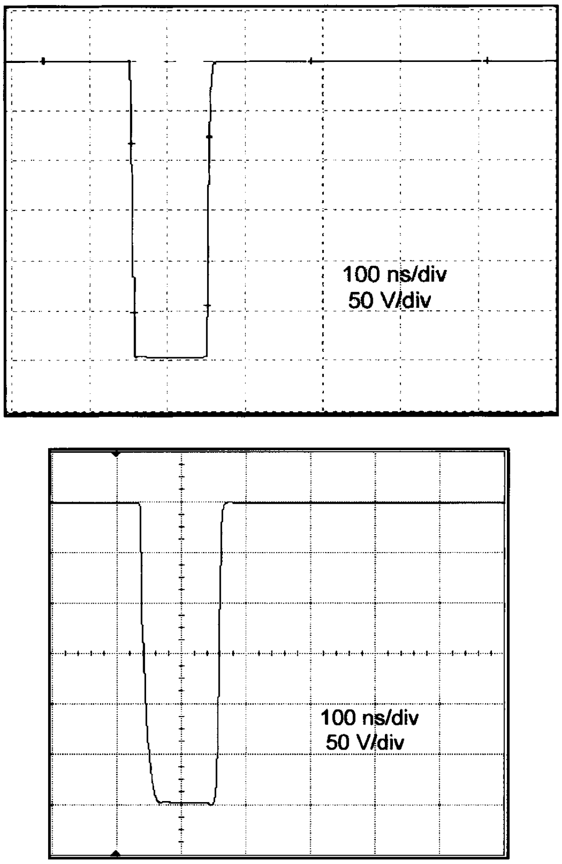

Fig. 10. Output pulses from the pulser. (a) The spice simulation of a 300 V output pulse driving a 50 Ω load. (b) Experimental 300 V output pulse of equivalent duration, driving a 50 Ω load.

RESULTS

Ultrasonic spike pulser can be tested using different kinds of resistive load : (1) With no any external load, (2) With 50Ω load, and (3) With ultrasonic transducer load.

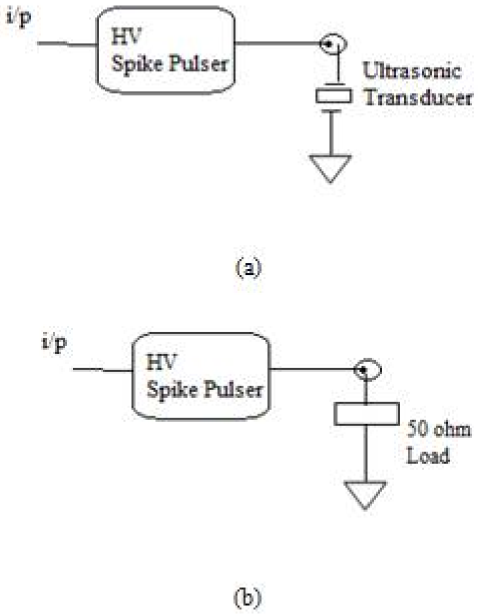

Fig.11.Different load condition for testing the performance of spike pulser: (a) With ultrasonic load and (b) With 50 Ohm load.

By using this above load we can check some parameters like :Input Pulse Width, Input PRT, Input Pulse mode, Charging Capacitance $C_{C,}$ Damping Resistance $R_{D,}$ External Load $R_{Load.}$ Fig.13. Output Pulse response of spike pulse with 50 Ohm load condition.experimental and simulation results are almost matched.

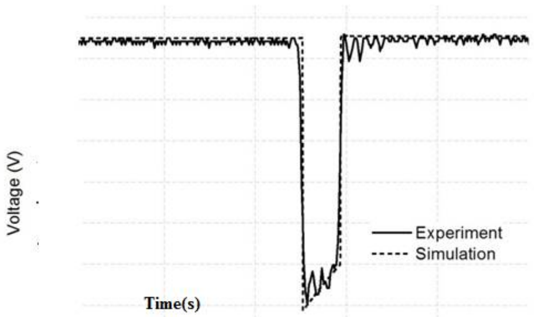

Fig.13. Output Pulse response of spike pulse with 50 Ohm load condition

CONCLUSION

The Ultrasonic Pulser Unit is designed for Non-destructive Testing/Evaluation (NDT/NDE) of fabricated mechanical components/parts.

1. Ultrasonic inspection of forgings for end fittings of PHWRs. End fitting is very critical mechanical component for the PHWR (pressurised heavy water reactors).
2. This pulser is used for Ultrasonic Inspection of Zircaloy-2 Pressure Tubes (PT) For PHWRs.[3].

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