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Nondestructive Testing and Flaw Detection in Steel block Using extension of Split Spectrum Processing based on Chebyshev IIR filter

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Abstract

Ultrasonic detection technique is used extensively in nondestructive evaluation of materials and flaws, precise location of micro-flaws, accurate estimation of the level of flammable fluids, mobile robots etc. Flaw detection in the presence of scattering noise is a remarkably challenging problem. Extension of Split Spectrum Processing based on variable bandwidth IIR filter is proposed to enhance the visibility of defect echoes and remove the scattering noise. The neural network is cascaded with the Split Spectrum Processing to improve the accuracy and resolution. The amplitude analysis of ultrasonic signal is also incorporated. This information is added to Time of Flight of ultrasonic signal to get more information of environment. Multiple flaws are possible to detect by the proposed method. The proposed method is superior to other techniques such as minimum, median, average and polarity threshold detectors.

Keywords-Target echo, Scattering noise, Split Spectrum Processing, Neural Network, Front Surface Echo, Back Surface Echo, Grain Echo, Time of Flight, Flaw detection.

1. Introduction

Ultrasonic non destructive testing is used to detect subsurface defects and anomalies in many materials together with material characterization and dimension analysis. They have got a wide range of applications such as detection of anomalies in welds, gears, nuclear power pressure vessels, aerospace components, aircraft maintenance heavy metals, forged products etc. Ultrasonic inspection has got many advantage such as high depth of penetration and higher sensitivity to surface and subsurface discontinuities. The ultimate industrial interest is to achieve high performance with less time using Ultrasonic testing.

A single piezoelectric transducer is used for the transmission and reception of the Ultrasonic signal. Butterworth van-dyke equivalent circuit model is used for modelling the ultrasonic transducer. It scans along the surface of the material and captures the signals that have been reflected from the back surface or from discontinuities such as defect or clutters in the steel block. In the presence of defect, the incident pulse is almost totally reflected. It contains all the frequency components. The arrival time of the reflected signal will give information about the depth at which the defect is present.

The main source of inaccuracy is the presence of scattering noise due to clutters in the metal block. The clutter and target (hole/defect) echo occupies same frequency range. So ordinary signal averaging cannot be applied. The amplitude analysis together with frequency diversity technique using Split Spectrum Processing is used to decorrelate the target echoes from the noise echoes. The amplitude information can be added with Time of flight information. Time of flight is the the time elapsed between transmission and reception of Ultrasonic signal. The Neural Network post processor is also cascaded to enhance the target visibility.

2. Transducer Modeling

Ultrasonic transducer is modeled using lumped parameter model defined by its transfer function. Butterworth Van-Dyke transducer model is used for this purpose. Acoustic and electric behaviors are modeled using two parallel branches. Acoustic branch represents dynamic behavior and it is an equivalent resonant circuit modeling the crystal resonator. Electric branch represents static behavior and it models the capacitance between the plates of the connection to the piezoelectric crystal. Voltage across the parallel capacitor C_p and voltage on the dissipative resistor Rd is used to derive the transfer

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function[2]. The transfer function for the transducer model is

$$G(s) = V_{Rd}(s) / V_{cp}(s) \quad (1)$$

$$G(s) = [R_dC_ss]/[\, s^2L_sC_s + s(R_sC_s + R_dC_s)+1] \quad (2)$$

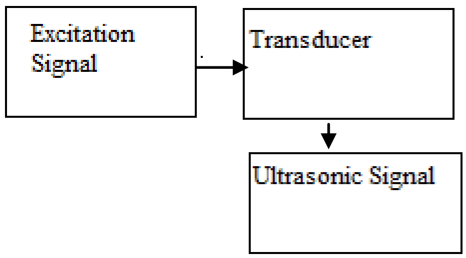

Fig.1.Ultrasonic signal generation

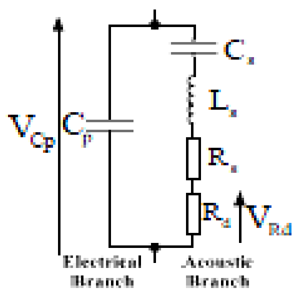

Fig.2. Butterworth Van-dyke Transducer equivalent circuit model[2]

3. Model Parameters

The received signal can be represented as delayed and attenuated version of the transmitted signal with the addition of additive white noise signal.

$$S_R(t) = A(t).S_T(t\text{-}TOF) + n(t) \quad (3)$$

n(t) : additive white noise

TOF : Time of flight

Amplitude of ultrasonic echoes depends on factors such as depth from which the signal get reflected, surface characteristics of reflector and shape of reflector surface[5].

Symbol	Description
C_p	Electrical Capacitance
L_s	Dynamic Inductance (α mass)
C_s	Dynamic Capacitance (α 1/ stiffness)
R_s	Dynamic Resistance
R_d	Output Resistance

Fig.3. Elements in Butterworth Van-dyke Transducer equivalent circuit model

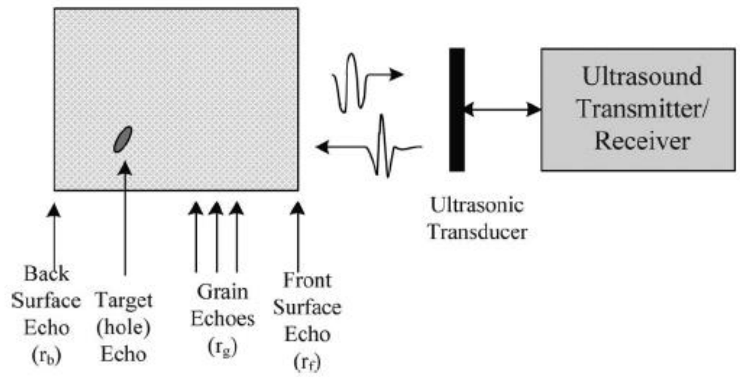

Fig.4.Ultrasonic testing set up using a steel block for the characterization of target(hole) echo and grain scattering.

Amplitude of ultrasonic echo received after reflection in a normal plane of a surface is[5]

$$A(t) = \frac{A0\ Cr\ \exp(-\alpha x(t))}{x(t)} \quad (4)$$

α : attenuation coeffient

Ao : Constant of transducer

Cr : Refelection coefficient

x : depth of penetration

$$x = V*TOF/2 \quad (5)$$

V : velocity of ultrasonic signal in material

TOF : Time of flight

Reflection Coefficient is used to model the total intensity reduction of ultrasonic beam reflected from a surface.

$$Cr = Ar_{eflected}/A_{incident} \quad (6)$$

The thickness of specimen under can be determined by calculating the time taken by transmitted signal to pass from front surface to back surface of the material, given the velocity of signal in the specimen is known. The arrival time (TOF) of the echoes also provide information about the depth of defect. Reduction in ultrasound intensity with distance (attenuation) is expressed in decibels per unit length. As depth of hole increases, attenuation also increases[8].

$$y= a*10^{bx} \quad (7)$$

a : 0.00980311

b : 0.00813188

The attenuation due to the presence of flaw as a function hole diameter can be expressed as

$$y = -.0212x +0.0724 \quad (8)$$

The target is usually larger in size with respect to the wavelength of ultrasonic signal and behave like geometric reflector. In the low frequency region, Target echoes exhibit dominant energy. Target echoes show a downward shift in their expected frequencies. But at high frequencies, the target echo information is suppressed because of attenuation effect due to scattering. The wavelength of incident wavelet is much larger than the size of scatters in the Rayleigh scattering region. This results in an upward shift in the expected frequency of ultrasonic scattering echoes. The Rayleigh scattering coefficient varies with the average volume of scatterer and the fourth power of the wave frequency.

$$\alpha_{Rayleigh} \propto D^3 f^4$$

4. Target Modelling

A 3D matrix is used to model the steel block.From the Ultrasonic C-Scan image, the gray scale image is obtained. The gray scale image will give the intensity values which shows amount of light reflected from each point. The intensity value varies between 0 and 1. If intensity of light reflected is high, then the value will be close to 1 and it will be seen as bright ares in the image. If the intensity of light reflected is less because of absorption, the intensity value will be closer to zero and will be appeared as darker areas in the image. The flaw will reflect light of all frequencies and do not have distortion unlike the noise whose frequency components will be absent or distorted. So flaw have high intensity value, between 0.8 and 1. Scatterers has intensity value between 0.1 and 0.3 as per the image and rest of the region has values less than $5*10^{-2}$ from where the light are not reflected due to the absence of discontinuities. These values are used to fill the 3D matrix to represent flaw, grains and plain areas.

5. Methodology

Front surface echo will be the delayed version of ultrasonic signal without material attenuation. It has highest amplitude and contains all the frequency components of the transmitted signal. So front echo can be detected with the help of a threshold detector with high amplitude threshold value. Front echo will give information about the surface characteristics of specimen under consideration. A large amplitude indicates flat and smooth surface while smaller amplitude indicates rough surface.

Rayleigh echo noises have discontinuities in their spectrum as many frequency components are lost due to absorption and scattering.The distribution of energy is not continous or even in the spectrum. But the flaws will reflect the signal completely and has no gaps in their frequency spectrum. Split Spectrum Processing(SSP) is used for the frequency analysis of the received spectrum in this case. SSP is based on the frequency diversity phenomenon where the frequency diversity between target and clutter echoes is taken into consideration. There are two main parts for SSP algorithm- Filter bank and recombination technique.

From the front echo spectrum, frequency range is selected upon which the Band pass filters can be applied.The main filter parameters are band pass filter type, number of filters, order of filters and overall bandwidth. IIR filters will give best performance with the SSP algorithm. Fourth order Chebyshev1 filter is proposed to build the filter bank. 10 band pass filters with different cut off frequencies are used to cover the frequency range that is selected from the front surface echo. When ultrasonic wavefront collides with a scatterer comparable to its wavelength, the scatterer will act as a spherical emitter generating more dispersion at high frequencies than at low frequencies[1]. Thus most of the target information remains in the lower frequency band.

The parametric equalizer is used to energy equalize the spectrum. When the SSP(Split Spectrum Processing) filter bank is applied to the flaw signal spectrum, all the resulting filter outputs have significant and non zero values. The minimum of the filter output is then taken and the flaw signal loss will be least. When the filter bank is applied to grain noise spectrum, some filter output will be very large and some other will give almost zero filter output. The minimum of the filter bank output in this case will give near zero value and thus reduces the grain echo[1].

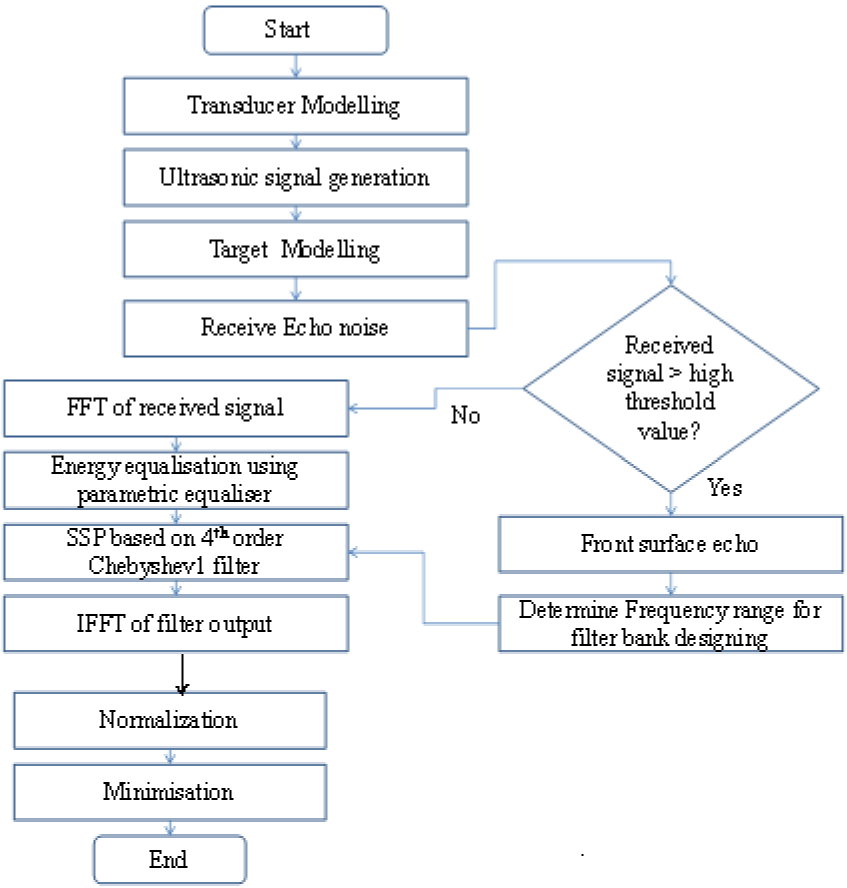

Fig.6. Flow Chart of flaw detection in steel block in the presence of Rayleigh scattering noise

6. Results

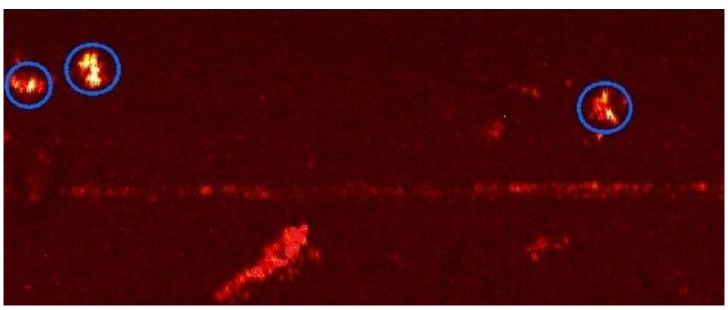

Fig.7. Ultrasonic Image of Steel block with flaws in circle

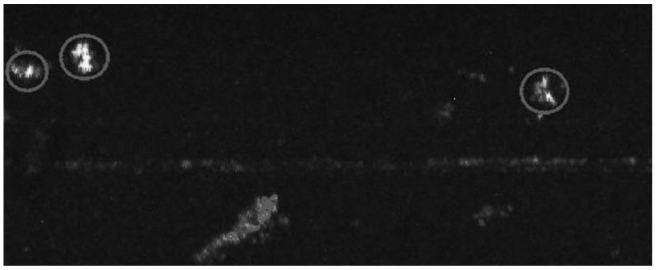

Fig.8. Gray scale Image of Steel block

Fig.9. Flaws having intensity above high threshold value

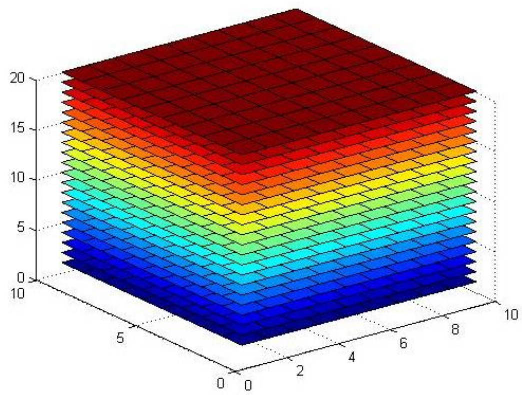

Fig.10. 3D matrix representation

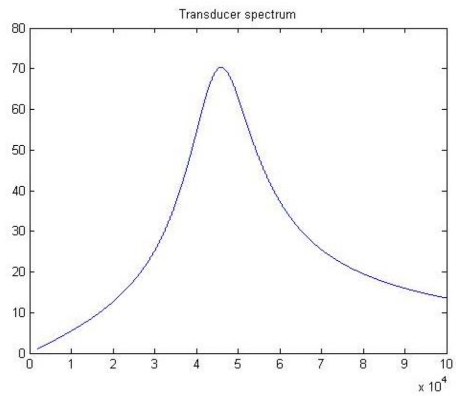

Fig.11. Butterworth Van-Dyke Transducer spectrum with bandwidth scaled to 2KHZ to 0.01MHZ

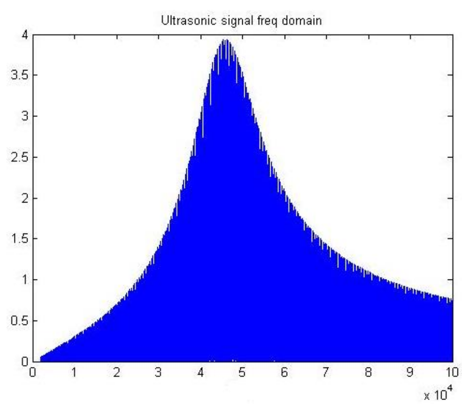

Fig.12. Ultrasonic Signal spectrum scaled to 0.01MHZ

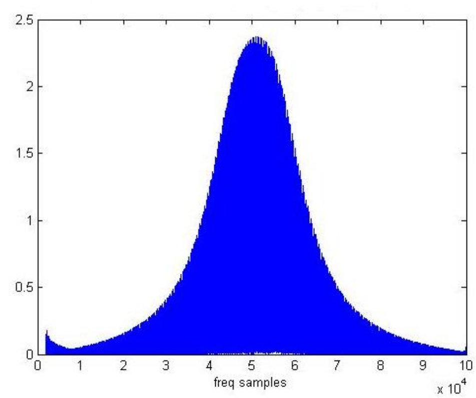

Fig.13. Flaw echo spectrum scaled to 0.01MHZ

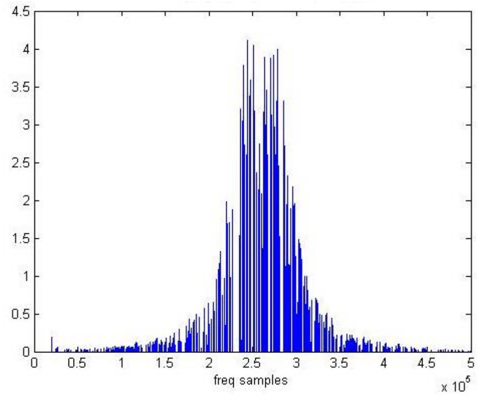

Fig.14. Back echo spectrum

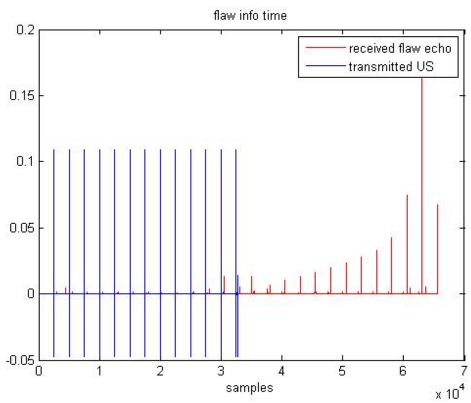

Fig.15. Ultrasonic transmitted signal and received Flaw echo pulses

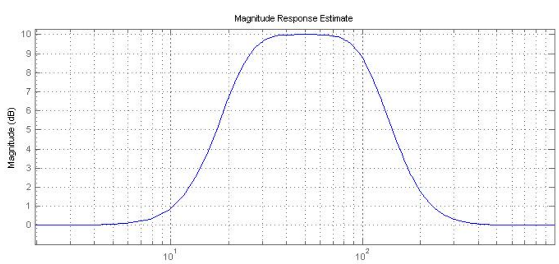

Fig.16. Magnitude response of Energy Equaliser

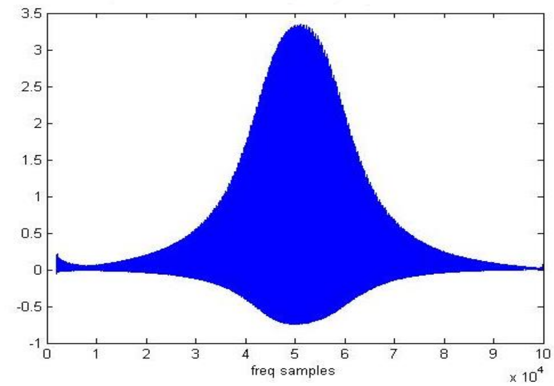

Fig.17.Energy Equalised Flaw spectrum

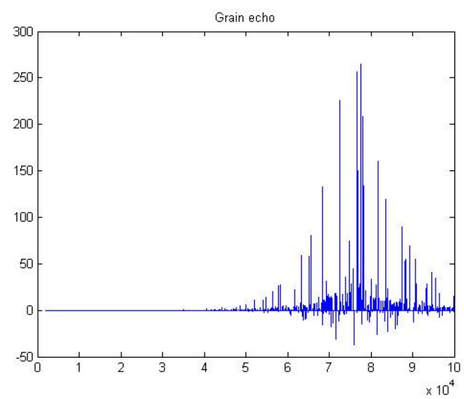

Fig.18. Rayleigh Grain echo spectrum scaled to 0.01MHZ

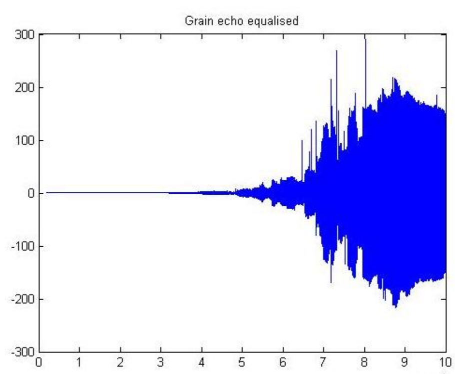

Fig.19.Energy Equalised Grain spectrum

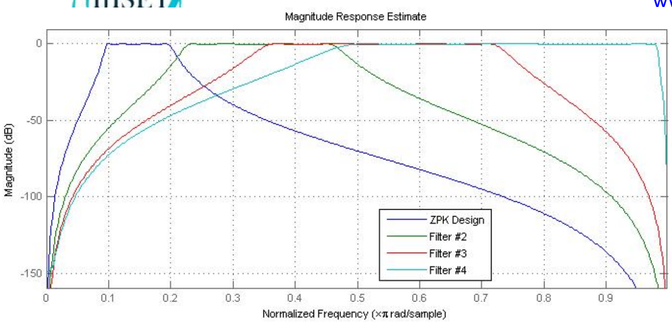

Fig.20. Variable Bandwidth Chebyshev1 IIR filter.

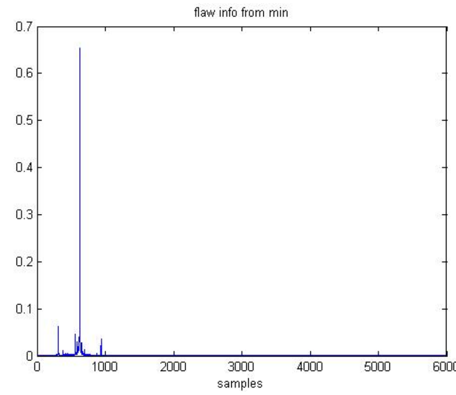

Fig.21.Detected Flaw echo Post Processing block output for different echoes

Echo type	Filter1 (normalized and minimised)	Filter2 (normalized and minimised)	Filter3 (normalized and minimised)	Filter4 (normalized and minimised)
Rayleigh grain echo	0	0.7518	10.6960	10.0670
Flaw echo	0.0125	0.1350	0.1648	0.0906
Back Echo	1.0e-003 * 0.0217	1.0e-003 * 0.0217	1.0e-003 * 0.4345	1.0e-003 * 0.2367

Table1. Post Processing block output for different echoes

7. Conclusion

SSP is a powerful technique which will give information about the frequency component present in the signal and time representation of the signal.Incorporating Variable bandwidth filter is a very attractive SSP method and is superior in performance and efficiency with respect to ordinary SSP method based on Fixed band Filters.The Chebyshev1 filters are zero phase IIR filters which are used for building filter bank and their performance are studied.

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