# Chapter book

"A New Condition Monitoring Approach for Maintenance Management in Concentrate Solar Plants"

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# Contents

Chapter 1

# A New Condition Monitoring Approach for Maintenance Management in Concentrate Solar Plants

**Carlos Quiterio Gómez Muñoz, Fausto Pedro García Marquez, Cheng Liang, Kogia Maria, Mohimi Abbas and Papaelias Mayorkinos**

**Abstract** The concentrated solar energy is one of the most important renewable energy source. It is crucial to ensure that the solar receivers work properly to avoid failures, and to increase the reliability, availability, safety and maintainability. Non-destructive testing (NDT) is used in structural health monitoring systems for fault detection and diagnosis (FDD). The main purpose of this paper is to present a novel approach for FDD based on long range ultrasonic technology, together with a signal processing of ultrasonic waves (Shear waves) employing wavelet transforms using a variable window size. A new electromagnetic acoustic transducer (EMAT) generates high frequency waves that flow through the material. A similar transducer is also employed as a sensor to collect the guided wave. These waves have a particular behaviour according to the condition of the material. It is analyse the influence of the temperature in the propagation of an ultrasonic pulse through the material. This information is very useful to carry out a proper signal analysis in order to find cracks or failures on the pipes, the correct operation of the system, etc.

**Keywords** Maintenance management · Concentrated solar plants · Wavelet transform · Electromagnetic acoustic receiver · Parabolic through receiver · High temperature ultrasonic signals

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## 1.1 Introduction

Non-destructive testing (NDT) for fault detection in structures have gained relevant attention in recent years due to significant advances in instrumentation technology and digital signal processing. Techniques for Structural Health Monitoring (SHM) permit to identify and diagnose the fault and its location on the basis of changes in static and dynamic structure features. In addition, these techniques can be remotely controlled and they may work online saving important costs associated to manual inspections and warning times. The capability of NDT to prevent faults is one of their main advantages, which typically achieve a better reliability, availability, maintainability and a cost reduction of the system [7, 13].

Within the NDT field, guided waves are a common technique employed for SHM. These waves are particularly useful in geometries such plates or tubes. This technology is based on the excitation of low frequency ultrasonic waves flowing along the pipeline over long distances and allowing inspections of large areas without any relocation of the actuator, as it occurs in classical ultrasonic methods [3]. This technology may be used in pipelines under working conditions and it can be inspected from a single position, what is particularly indicated when monitoring inaccessible areas, e.g. isolated materials, partially buried structures, corrosive atmospheres or structures under the sea [15]. Since these signals can be recorded and processed, novel methodologies are arising so as to perform predictive analysis in real time.

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The temperature can cause structural problems in the medium and long-term. Note that this study is crucial since the cost of PTR can reach the 30% of the overall solar field cost. Therefore, the correct maintenance of the receivers is of paramount importance to assure that CSP plants work properly [6, 10]. The average annual PTR replacement rate from 1997-2001 was about 5.5% [14]. Nowadays, it has been reduced to 3.37% [10] and forecasts indicate that the replacement rates should decrease up to 0.5% for a near future [14].

The FDD proposed is able to detect faults or structural modifications, e.g. scratches, cuts, changes in thickness or edges by identifying pattern changes in the input-ouput signals [11]. The signal processing is based on system identification techniques in discrete time to estimate potential changes, employing Wavelet Multisignal Analysis in one dimension will be employed to identify the structure at different temperatures.

## 1.2 A New Electromagnetic Acoustic Transducer for Condition Monitoring

The Electromagnetic Acoustic Transducer (EMAT) (Fig. 1.1) is a transducer for non-contact sound generation and reception using electromagnetic mechanisms. It has been widely used in non-destructive testing in the generation of Shear and Lamb waves [2]. A new EMAT has been developed specifically for this purpose, with a specific configuration of coil and magnets.

Considering the dimension of the pipe (outer radius 35 mm ) and the review on EMAT configuration, a design of the EMAT transducer for this application is shown in Fig. 1.2, using PPM and race track coil to generate SHO mode in a plate or equivalent $T(0,1)$ mode in a pipe. The dimension of each magnet is 15 mm $\times$ 5 mm $\times$ 5 mm. The distance between magnets is 1 mm. In addition, the magnetic strength of each magnet is $0.3T$. The diameter of coil is 0.315 mm and the width and length are 15 mm and 35 mm respectively with a lift-off distance 0.1 mm to the sample.


**Fig. 1.1** Picture of 1st generation EMAT transducer

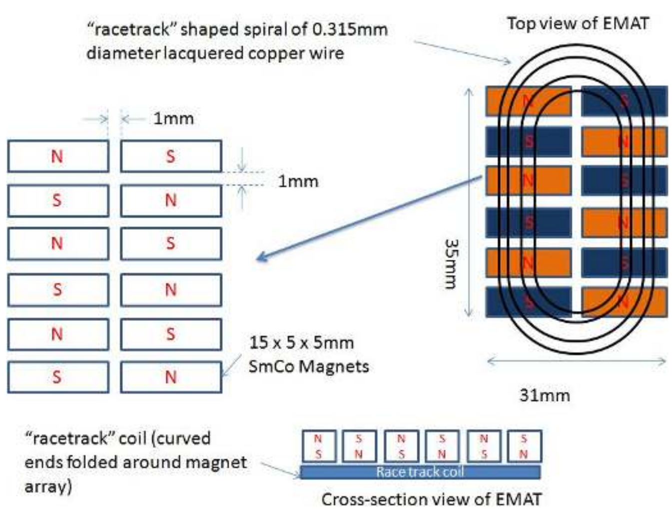


**Fig. 1.2** First generation EMAT transducer

The type of EMAT configuration shown in Fig. 1.3 is mainly to detect transversal defects (spiral cracking, blowout holes, circumferential cracking, bell splitting, etc.). In this case, Lorentz forces are generated normal to the tube wall, and so that the compressive forces produce ultrasound propagating along longitudinal direction through the tube/pipe for inspection.

## 1.3 Experiments

An experimental platform that comprises a high power pulser-receiver and a condition monitoring system based on electromagnetic acoustic transducers placed on an austenitic stainless steel plate is designed in order to illustrate the results. The plate material is the same as that used in the solar concentration pipes (316*Ti*, standard carbon 3116 Type with titanium stabilisation). The properties of this material and the influence of temperature thereon is found in Table 1.1.

The plate is heated with a heater pad for the tests of emission and reception of ultrasonic pulses by the EMAT from 40 °C to 180 °C (see Fig. 1.5). Each test

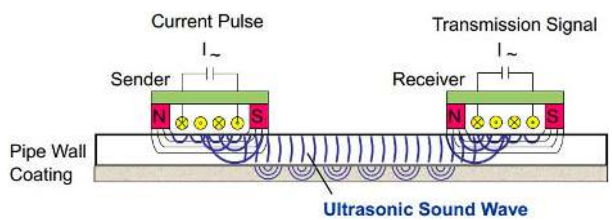


**Fig. 1.3** Principle of EMAT transmitter and receiver for longitudinal inspection

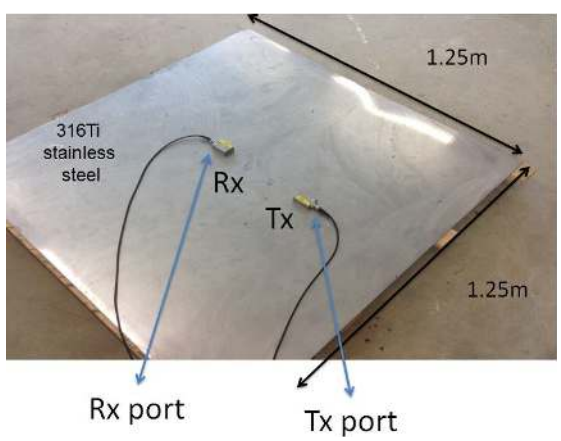


**Fig. 1.4** Placement of the EMAT on austenitic steel plate

**Table 1.1** Physical properties of 316*Ti* steel and the influence of temperature.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Thermal expansion | $10e^{-6} \times Ke^{-1}$ | | 16.5 | 17.5 | 18 | 18.5 | 19 |
| Modulus of elasticity | longitudinal Gpa | 200 | 194 | 186 | 179 | 172 | 165 |
| Poisson number | $\mu$ | 0.3 | | | | | |
| Electrical resistivity | $\Omega$mm$^2$/m | 0.75 | 0.79 | 0.87 | 0.94 | 0.98 | 1.02 |
| Electrical conductivity | Siemens·mm$^2$/m | 1.33 | | | | | |
| Specific Heat | J/(kg·K) | 500 | 500 | 520 | 530 | 540 | 540 |
| Density | kg/dm$^3$ | 8 | | | | | |
| Thermal conductivity | W/mK | 15 | 16 | 17.5 | 19 | 20.5 | 22 |
| Relative magnetic permeability | $\mu\gamma$ | 1.02 | | | | | |
| Temperature (°C) | | 20 | 100 | 200 | 300 | 400 | 500 |

was performed when the temperature increased 10 °C. It has been used a 6 cycles Hanning pulse with a frequency of 256 kHz to excite the EMAT.

## 1.4 Wavelet transform

Wavelet transform (WT) improves the limitations of resolution and the loss of information presented by the Short-Time Fourier Transform or the Fast Fourier Transform [5]. This technique uses a variable window size, using large windows where it is required accuracy in low frequencies, and using small windows where the information is in the high frequencies. Other way to understand the operating mode of the WT is to think that the signal passes through a low pass filter and high pass filter. The resulting signal from low pass filter is the approximations $A_i$, and the re-

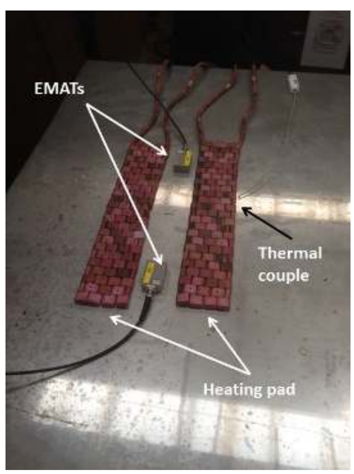


**Fig. 1.5** Heater pad on the plate

sulting signals from the high pass filter are the details $D_i$ (Fig. 1.7), where $c$ is the subsampling. For discrete signals it can be applied single-level or multi-level filters. The sum of the approximations and details should be given as a result the original signal.

Wavelet transforms are commonly categorized as Continuous Wavelet Transforms (CWT), Discrete Wavelet Transforms (DWT), Wavelet Packet Transforms (PWT) among others [4, 8]. The mother wavelet, which is given by the Eq. 1.1.

$$\Psi_{s,T}(t) = \left(\frac{1}{\sqrt{s}}\right)\Psi\left(\frac{t-T}{s}\right), \tag{1.1}$$

where $s$ is the scale factor, and $\tau$ is the translational factor. The wavelet transform $W_{f(s,\tau)}$ of a function $f(t)$ is the decomposition of $f(t)$ in a set of functions forming a base with the conjugate of the mother wavelet $(\psi * s, \tau_t)$. It is defined in Eq. 1.2:

$$W_{f(s,T)} = \int f(t)\psi^*_{s,T}(t)dt. \tag{1.2}$$

The most recurrent families of wavelet transforms are Haar, Daubechies, Biortogonal, Coiflets, Morlet or Symlet transforms. The selection of a particular family can be set by the application where the wavelet is introduced [12].

It was used a multi-signal analysis, to analyse different scenarios together, and it is obtained the energy of each signal. On the other hand it is obtained the percentage

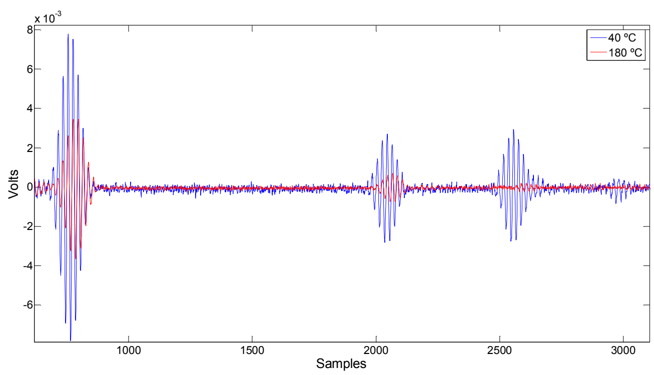


**Fig. 1.6** Signals obtained by the EMAT with the plate at 40 °C and 180 °C

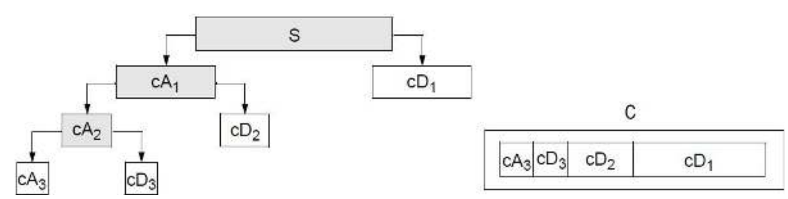


**Fig. 1.7** Wavelet decompositions levels with subsampling

of information of the decompositions in each signal. It was used the daubechies wavelet family, which according to [9] are the most suitable for this type of signals, because it are more sensitive to sudden changes. The number of levels that reports best results was five. Fig. 1.5 shows the five levels of decompositions with their respective frequencies for the signals obtained in the experiments.

## 1.5 Results

Table 1.2 shows the results after the analysis of the signals for each temperature of the steel plate. It is showed the resulting energy for each signal according to the chosen wavelet decomposition, and it is also presents the percent of information of each of the five decompositions (approximation and details). In all cases the D4 decomposition contains the highest percentage of information of the original signal ant it is associated with the frequency range 156 kHz-312 kHz. And it is consistent with the excitation frequencies of the Hanning pulse used in the actuator (256 kHz). This allowed study the frequencies of interest from other frequencies.

Fig. 1.9 shows that D4 wavelet decomposition present the main percentage of energy of the signal in the frequency range of 156-312 kHz, which is consistent since the excitation ultrasonic pulse is 256 kHz. Finally a multi-signal processing analysis employing wavelet transforms is done, providing a value of energy for each signal.

Fig. 1.10 shows that the energy decreases exponentially with increasing temperature. This is due to, although the frequency remains constant, the signal amplitude decreases as the temperature increases because it changes the parameters such as Young's modulus and Poisson's ratio and this affects the velocity of wave propagation.

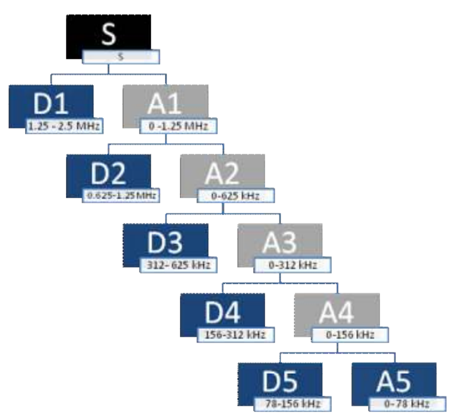


**Fig. 1.8** Wavelet decompositions levels for ultrasonic signals received by the EMAT

**Table 1.2** Please write your table caption here

| Wavelet Decompositions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | D1 | D2 | D3 | D4 | D5 | A5 | Energy |
| Temperature (°C) | 40 | 0.48% | 0.47% | 8.16% | 89.64% | 0.14% | 1.10% | 2.82E-03 |
| | 50 | 0.10% | 0.26% | 7.56% | 90.44% | 0.10% | 1.55% | 2.35E-03 |
| | 60 | 0.13% | 0.37% | 7.39% | 89.82% | 0.25% | 2.04% | 1.84E-03 |
| | 70 | 0.14% | 0.42% | 7.19% | 89.31% | 0.49% | 2.45% | 1.49E-03 |
| | 80 | 0.17% | 0.50% | 7.04% | 89.14% | 0.68% | 2.47% | 1.19E-03 |
| | 90 | 0.20% | 0.65% | 7.03% | 88.87% | 0.74% | 2.51% | 9.96E-04 |
| | 100 | 0.24% | 0.76% | 6.95% | 89.01% | 0.79% | 2.25% | 8.32E-04 |
| | 110 | 0.28% | 0.94% | 6.86% | 89.34% | 0.64% | 1.94% | 6.98E-04 |
| | 120 | 0.35% | 1.03% | 6.68% | 89.74% | 0.47% | 1.73% | 5.76E-04 |
| | 130 | 0.37% | 1.09% | 6.61% | 89.88% | 0.30% | 1.74% | 5.32E-04 |
| | 140 | 0.38% | 1.11% | 6.68% | 90.05% | 0.17% | 1.62% | 5.11E-04 |
| | 150 | 0.40% | 1.09% | 6.79% | 90.17% | 0.14% | 1.41% | 5.13E-04 |
| | 160 | 0.39% | 1.09% | 6.61% | 90.55% | 0.18% | 1.19% | 5.15E-04 |
| | 170 | 0.49% | 1.14% | 6.61% | 90.40% | 0.17% | 1.18% | 5.04E-04 |
| | 180 | 0.49% | 1.14% | 6.61% | 90.40% | 0.17% | 1.18% | 5.04E-04 |

## 1.6 Conclusions

The development of condition monitoring techniques together with the use of advanced signal processing approaches to reduce the failure rate of Parabolic Trough Receivers (PTR) has been done in order to increase the reliability, availability and investing returns in the generation of electricity by means of solar energy. PTR works at high temperatures where the properties of the ultrasonic inspection is affected. This work reports a novel methodology to control the condition of the PTR steel part by means of ultrasounds and digital signal processing. Particularly, a method

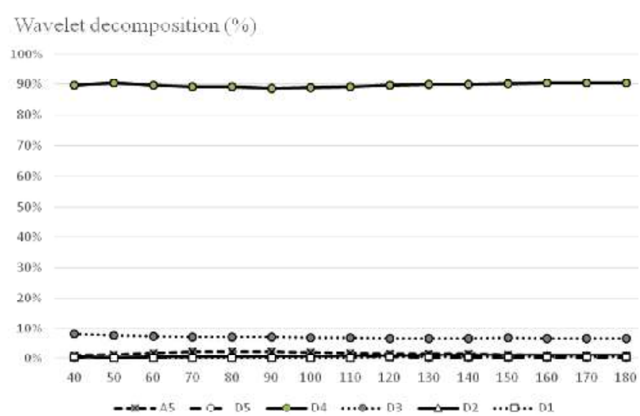


**Fig. 1.9** Percentage of signal information in each decomposition

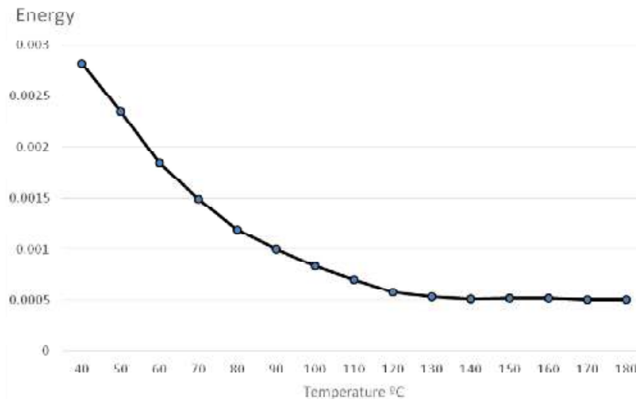


**Fig. 1.10** Energy of ultrasonic signals for each temperature

for identifying changes in the ultrasonic signals due to changes in temperature is crucial to detect any anomaly in the pipes with greater efficiency.

Significant discrepancies between the energy measurements can work as an alarm signal to activate maintenance operations. Case studies based on laboratory experiments have been done in order to demonstrate this novel approach.

## 1.7 Acknowledgements

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