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“Techno-Economical Advances for Maintenance Management of Concentrated Solar Power Plants”

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Chapter 1

Techno-Economical Advances for Maintenance Management of Concentrated Solar Power Plants

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Abstract Concentrated solar power (CSP) capacity has experimented a high growing worldwide. Nowadays, CSP industry is focus on decrease the operation and maintenance (O&M) costs and to set the adequate non-destructive testing techniques to inspect the plants. The implementation of Condition monitoring system will reduce O&M costs and energy losses. The main objective of this paper is to present a review of the condition monitoring techniques for solar absorber tubes, insulated pipes and storage tanks of parabolic trough and linear Fresner receiver plants.

Keywords Concentrated solar power · Condition monitoring · Non-destructive testing · Maintenance management

1.1 Introduction

The growing electricity demand, the effects of climate change and the depletion of fossil fuels make the need for clean, stable and affordable renewable energy sources. The electricity generated by renewable energies is growing in the last few years, and CSP appears as a promising renewable source. Nowadays CSP technology has a reduced share of the total renewables energies capacity worldwide [19]. The forecast studies show that CSP has increased the installed capacity more than 1000% from 2006 (see Fig.1.1) [19]. The levelized cost of electricity (LCOE) is defined as the cost of the electricity generation. It is used to compare the cost of generation among

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different technologies. The LCOE in 2014 for onshore wind energy is from 60 to 95 USD/MWh, and hydro energy is from 40 to 120 USD/MWh [18]. The LCOE for CSP is from 150 to 220 USD/MWh [18], and it reveals that CSP energy is more expensive than wind or hydro energy due to the maturity of these energy technologies. Fig. 1.2 shows the projections of the international energy agency for the LCOE of new-built CSP plants. The LCOE decreases in the forthcoming years very fast and then will be stable at 70 USD/MWh in 2050.

The operating costs of CSP plants are low compared to fossil fuel-fired power plants, but are still significant. O&M costs for CSP plants are around 0.04 USD/kWh [17]. The replacement of receivers and mirrors must be often carry out due to failures or damages being a significant part of maintenance costs. For example, the replacement of a solar absorber tube is around 1000 €, i.e., € 0.5 Million per annum for a 50 MW CSP plant [30].

Nowadays, CSP plant operators carry out more corrective maintenance tasks than preventive maintenance tasks. The automation of maintenance tasks and an adequate real-time diagnostics will reduce O&M costs, as well as improve performance [17]. The reliability, availability, maintainability and safety (RAMS) of CSP plants must be improved using efficient and cost-effective techniques of inspection. This paper is focus on the review of the inspection techniques.

1.2 Concentrated Solar Plants

The CSP plants employ mirrors to concentrate a large amount of solar rays on a solar receiver where a working fluid is flowing. Working fluid such as oil, molten

Fig. 1.1 Worldwide CSP installed capacity (data from [19])

Fig. 1.2 Projections of LCOE for new-built CSP plants [2]

salts, steam or air is heating to be used through a heat exchanger for the generation of steam. Then, a steam turbine generate electricity. If the working fluid is steam, it will be directly fed to the steam turbine. Thermal storage tanks are usually used between the solar field and the heat exchanger of the steam turbine. Fig. 1.3 shows a scheme of a typical parabolic trough plant.

Fig. 1.3 Scheme of a parabolic trough plant [26]

Nowadays, there are four different available and implemented of CSP technologies: parabolic trough, linear Fresner reflector, parabolic dish system and solar power towers [49]. Table 1.1 shows CSP technologies depending on the type of focus (line or point focus) and receiver type (fixed or mobile receivers). Solar power towers employ volumetric solar receivers which are difficult to inspect with the current available techniques. Parabolic trough system is the technology most implemented [27] and employs absorber tubes, as receivers, with a complex morphology to inspect (Fig.1.4).

1.3 Maintenance Theory

Maintenance is necessary to ensure the good operation of the components. The basic objectives of the maintenance activity are to deploy the minimum resources required to ensure that components perform their intended functions properly, to ensure system reliability and to recover from breakdowns [21].

Fig. 1.4 Absorber tube [26]

Table 1.1 Main CSP technologies [2].

Receiver type	Focus type	
	Line focus: Collectors track the sun along a single axis and focus irradiance on a linear receiver. This makes tracking the sun simpler.	Point focus: Collectors track the sun along two axes and focus irradiance at a single point receiver. This allows for good receiver efficiency at higher temperatures.
Fixed: Fixed receivers are stationary devices that remain independent of the plant's focusing device. This eases the transport of collected heat to the power block.	<p>Linear Fresnel reflectors</p>	<p>Towers</p>
Mobile: Mobile receivers move together with the focusing device. In both line focus and point focus designs, mobile receivers collect more energy.	<p>Parabolic troughs</p>	<p>Parabolic dishes</p>

1.3.1 Corrective, Scheduled and Condition Based Maintenance

Classical theory sees maintenance as either corrective or preventive. The former (also known as unscheduled or failure based maintenance) is carried out when any component of the CSP plant break down and when faults are detected or failures occur in any of the components. Immediate refurbishment or replacement of parts may be necessary [3] and unscheduled downtime will result. Corrective maintenance is therefore the most expensive of strategies and CSP plant operators will hope to resort to it as little as possible. By contrast, the objective behind preventive maintenance (PM) is to either repair or replace components before they fail [3]. This has most straightforwardly been achieved by scheduled maintenance, also known as time based (or planned) maintenance and involving repair or replacement at regular time intervals as recommended by the supplier and regardless of condition. Scheduled maintenance tasks in CSP such as the cleaning of mirrors.

But reducing failures in this way comes at the cost of completing maintenance tasks more frequently than absolutely necessary and not exhausting the full life of the various components already in-service. An alternative is to mitigate against major component failure and system breakdown with condition based maintenance (CBM) in which continuous monitoring and inspection techniques are employed to detect incipient faults early, and to determine any necessary maintenance tasks ahead of failure [33]. This involves acquisition, processing, analysis and interpretation of data and selection of optimal maintenance actions [45] and is achieved using condition monitoring systems [11]. CBM has been shown to minimise the costs of

maintenance, improve operational safety, and reduce the quantity and severity of in-service system failures.

1.3.2 Reliability Centred Maintenance

Reliability centred maintenance (RCM) has been formally defined as “a process used to determine what must be done to ensure that any physical asset continues to do whatever its users want it to do in its present operating context” [24]. It involves maintaining system functions, identifying failure modes, prioritizing functions, identifying PM requirements and selecting the most appropriate maintenance tasks [43] with the objective of managing system failure risk effectively [22]; operational and maintenance policies are optimized such that the overall maintenance task is reduced [3]. RCM has been recognized and accepted in many industrial fields, such as steel plants, railway networks, ship maintenance and other industries.

1.4 Inspection Techniques

There are many components and parts of a CSP plant to be inspected. Some of these components must to be inspected without insulation or working fluids, therefore, outages must be realized to carry out these inspections. Outages are related with production losses but inspections are necessary to ensure the good operation of the plant. This section presents the characteristics of each inspection technique available for CSP parabolic troughs and linear Fresnel reflectors. Table 1.3 presents a summary of the characteristics of each technique explained next and the related references from literature.

(1) Visual Inspection

The personal of maintenance carry out the visual inspection (VI) of the structural components of the CSP plant frequently. Large visible effects on surfaces, damaged insulation, working fluid leaks, missing components or dust on mirrors are some of the detectable damages by this technique. Not all the components can be inspected in the operation of the plant. The visual inspection of insulated components or internal surfaces of the tanks must be carry out during outages due to the necessary removal of the insulation from pipes or the empty of storage tanks [30]. This technique can be automated by remotely controlled vehicles with video cameras, i.e. automated vision inspections (AVI). Planned outages are necessary to realize the visual inspection of the internal surface of pipes by robots with video cameras, i.e. the pipe crawling inspection robots (PCIR) [39, 50].

(2) Liquid Penetrant Inspection

Liquid penetrant inspection (LPI) is realized by certified inspection personnel to detect surface-breaking defects visually. A special dyes are spread over the surface to inspect such as welds. Then, a developer is applied showing a visible indication

of the defect. Outages are necessary for the application of this technique to insulated pipes or internal surfaces of empty tanks [14].

(3) Magnetic Particle Inspection

Magnetic particle inspection (MPI) consists on to magnetise the surface area to inspect that it is previously sprayed with ferrous particles. In the case of a breaking-surface, the magnetic flux make the alignment of the ferrous particles sprayed before, indicating the location of the damage to the maintenance personnel. MPI is employed in the inspections of ferrous components such as ferrous pipes of the secondary coolant system, cold storage tanks or welds. This technique is a visual inspection technique not applicable for components manufactured from austenitic stainless steel grades [14].

(4) Magnetic Flux Leakage Inspection

Magnetic Flux Leakage (MFL) inspection is an electromagnetic technique of Non-Destructive Testing method to detect pitting, general corrosion and cracks. It is based on magnetising the ferrous component to inspect with a powerful magnetic field. If the component has not defects the magnetic flux lines will remain undisturbed. Nevertheless, where there is a defect the magnetic flux will leaks from the component. This technique employs a MFL testing device based on Hall-effect and capable to record the magnetic flux leakages. MFL is used in insulated ferrous pipelines, heat exchanger tubes or cold storage tanks. The removal of insulations is necessary to apply MFL [1, 9, 41].

The potential of Pulsed Magnetic Flux Leakage (PMFL) technique has been demonstrated in [48] to find damages on insulated steel pipes.

(5) Eddy Current Testing

Eddy Current (EC) testing employs electromagnetic induction to detect discontinuities in conductive materials. Eddy current is based on the changing magnetic field generated in a coil when alternating current is applied. If the coil is brought near of the surface of a conductor, the magnetic field of this excited coil generate “eddy” current within the conductor. Additionally, the Eddy current induced in the conductor generate their own magnetic field (Lenz’s Law) opposed to the magnetic field generated by the excited coil. This secondary magnetic field will fluctuate when surface or near-surface defects are presented in the component varying the impedance of the sensing coil. The identification and definition of damages can be evaluated by these impedance changes [12, 13].

Pulsed EC is able to detect pitting corrosion or cracks in pipelines when the insulation is removed and microstructural changes of both the cermet coating and substrate of the solar absorber tube [38, 44].

(6) Alternating Current Field Measurement

Alternating Current Field Measurement (ACFM) is useful for the detection and identification of surface breaking defects such as corrosion and cracks. This technique is similar to EC, but ACFM take into account the AC field changes generated around the defects instead of the impedance in EC. Sensing coils orientated are able to detect both depth and length of the surface defect [47]. ACFM is used to detect and identify fatigue cracks in welds. Pipelines and the outer area of absorber tubes

can be inspected with this technique. The resolution of ACFM is poor and increase dramatically when the insulation is removed [31, 32].

(7) Radiographic Inspection

Radiographic imaging of structural components using X-rays provides useful information regarding the structural condition of the component being inspected. Radiographic imaging depends “on the different level of absorption of X-ray photons as they pass through a materia” [37]. A transportable radiographic system can be implemented in CSP such as in wind farms, where it was demonstrated as “a solution to find defects and reduce the cost of inspection” [10]. Nowadays, radiographic digital inspection is available using digital records [36].

Radiographic inspection can be carry out in operation without the removal of insulations. This technique allows to detect corrosion and weld defects in tubing, piping and storage tanks [35, 51]. A statistical guide of the condition of the plant can be developed using radiographic inspection [30].

(8) Ultrasonic Testing

Ultrasonic testing (UT) is generally employed for the detection and qualitative assessment of surface and subsurface structural defects [6, 21]. Ultrasonic wave propagation characteristics allow estimation of the location and type of defect detected, thus providing a reliable method of determining the material properties of the components. UT is based on piezoelectric transducers ultrasonically coupled on the surface of the component to be inspected [28, 29]. Cracks and corrosion in pipelines and storage tanks can be detected with this technique if the insulation is removed previously. UT can be used for the inspection of supporting structures [30].

(9) Long Range Ultrasonic Testing

Long Range Ultrasonic Testing (LRUT) is carried out by piezoelectric transducers fitted around a pipe using and inflatable ring within a small pipe length where the insulation has been removed [30]. LRUT is used to evaluate long sections of welded pipes and tubes detecting corrosion and cracks [5, 25, 40, 42]. Absorber tubes can be evaluated with this technique. LRUT is carry out during outages unless pipes or tubes are below 100°C [23, 30].

(10) Electromagnetic Acoustic Transducers

Electromagnetic Acoustic Transducers (EMATs) is a UT technique employing non-contact electromagnetic sensors capable of generating and receiving ultrasonic waves. EMAT is useful for automated inspections and it is able to work under high temperature conditions or dry [4, 7, 8, 15, 15, 16]. Outages of CSP plant are not necessary to apply this technique. It is easy to produce specific waves and modes such as Rayleigh waves used in absorber tubes and insulated pipes inspections [30].

(11) Infrared Thermography

Infrared (IR) thermography inspection is carry out by expensive infrared cameras. This technique is used to detect damaged insulation, leaks and heat losses in the plant [20], but it is difficult to detect structural defects. Absorber tubes can be inspected with this technique providing an idea of the overall condition of the plant [34].

(12) Acoustic Emission

Rapid release of strain energy takes place and elastic waves are generated when the structure of a metal is altered, and this can be analyzed by acoustic emissions (AE) [23]. Very sensitive piezoelectric sensors are employed by this technique. AE is able to detect and monitor defects such as corrosion, cracking and leaks providing qualitative information (presence and location of the defect) to the maintenance staff. The structural health monitoring of storage tanks can be achieved by AE. Corrosion debris, corrosion detection and crack initiation and propagation can be detected in pipes or tubes of the CSP plant by AE [30].

(13) Electrical Effects

For the optimal performance of the plant, the rays of the sun reflected by the mirror must be precisely focus on the receiver. Electrical motors used for the alignment of mirrors or sun sensors can fail, for this reason the continuous monitoring is performed using voltage and current measures [23].

1.5 Conclusions

Nowadays, CSP industry is focus on decrease the LCOE through the reduction of O&M costs and to set the adequate techniques to inspect the plants. The implementation of Condition monitoring system will reduce O&M costs and energy losses. A review of the main condition monitoring techniques for some components of Parabolic Trough and Linear Fresner receivers Plants has been carried out. Specifically, components such as solar absorber tubes, insulated pipes and storage tanks.

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Table 1.2 Characteristics of each Technique and references from literature (1)

Technique	Used in	Carry out by	Detection capability	Outages	References
Visual VI	Structural components	Personnel	Large visible effects on surfaces, damaged insulation, leaks, missing components, dust on mirrors	necessary for insulated components or internal surfaces of the tanks	[30]
	AV Structural components	Remotely controlled vehicles	Large visible effects on surfaces, damaged insulation, leaks, missing components, dust on mirrors	necessary for insulated components	[39]
	PCIR Internal pipes	Robots	only for visible defects	yes	[50]
	LPI Welds	Certified inspection personnel	Small surface-breaking defects such as fatigue cracks and corrosion pits of the tanks	necessary for insulated components or internal surfaces	[14]
	MPI Ferrous pipes (secondary coolant system), cold storage tanks, welds	Strong portable electromagnet device	Small surface-breaking defects, very near-surface cracks and corrosion pits	necessary for insulated components or internal surfaces of the tanks	[14]
MFL	Insulated ferrous pipelines, heat exchanger tubes and cold storage tanks	Hall-effect sensor/bulky equipment	Pitting, general corrosion and cracks	not for CMFL	[1, 9, 41, 48]
ECT	Pipelines, absorber tubes	Eddy current sensor, robotic crawlers	Surface and near-surface defects (cracks and pitting corrosion), general corrosion, microstructural changes	without insulation	[12, 13, 38, 44]

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Table 1.3 Characteristics of each Technique and references from literature (2)

Technique	Used in	Carry out by	Detection capability	Outages	References
ACFM	Welds, pipelines and the outer area of absorber tubes	Pigs, robotic crawlers pitting corrosion cracks and fatigue	Surface-breaking defects including removed	better resolution if insulation is	[31, 32, 47]
Radiography	Tubing, piping and storage tanks	Transportable radiographic system	Internal and surface defects associated with corrosion and weld inclusions	no	[10, 35, 37, 51]
UT	Pipelines and storage tanks	Piezoelectric transducers	Internal and surface defects including fatigue cracks and corrosion	removal of insulation	[6, 9, 21, 28, 29]
LRUT	Piping, tubing, absorber tubes	Ring of piezoelectric transducers	Large hidden and surface breaking defects. Relatively severe corrosion and transverse cracks	no if < 100°C/ requires removal of insulation only in the area of installation	[5, 23, 25, 40, 42]
EMATs	Absorber tubes and insulated pipes	Piezoelectric transducers	Surface and hidden defects including corrosion and fatigue cracks	no	[4, 7, 8, 15, 16, 46]
IR	in general	IR cameras	Heat losses and leak detection	no	[20, 34]
AE	Storage tanks, pipes and tubes	Very sensitive piezoelectric sensors	Corrosion, cracking, leaks	no	[20, 23, 30, 33]
Elec. Effects	Elect. Motors of the mirrors structure.	Electrical sensors	Electrical or mechanical damages	no	

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