Application of IR Thermography as a Condition Based Preventive Maintenance Technique for Energy Conservation in Pulp and Paper Industry

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ABSTRACT

In recent years, infrared (IR) thermography has emerged as a widely used method for nondestructive procedures. IR Thermography offers noncontact wide area detection of subsurface temperature and related defects. This technique can be used as an alternative or complement to conventional inspection methods in a plant. The most interesting aspect of the IR thermography is ease in its operation and prediction of maintenance, thereby resulting in saving of cost in a plant. In the present article IR thermography is presented as a preventive maintenance technique to identify energy conservation potential by adopting it as a regular maintenance procedure. Case studies conducted in pulp and paper mills are presented to identify energy saving potential of thermography in a mill.

Introduction

Condition based (CB) preventive maintenance is widely used in Industry to maintain the healthy condition of assets and to perform maintenance when it is needed at the most opportune time. It helps to reduce operating costs and increase the safety of assets. These maintenance practices are economical and also provide opportunities for cost reduction.

Various techniques are used for condition based preventive maintenance and thermography is one of the techniques for condition based maintenance. Thermography involves the use of infrared imaging and measurement devices to display and measure thermal energy emitted by an object. IR thermography cameras produce images of invisible infrared or heat radiation and provide precise noncontact temperature measurement capabilities (1).

Infrared cameras are extremely cost effective diagnostic tools and can be used for diverse applications. An infrared camera, as a non-contact device, detects infrared energy (heat) and converts it into an electronic signal. The signal is processed to produce a thermal image on a video monitor and to perform temperature calculations. Heat sensed by an infrared camera can be very precisely quantified, or measured to monitor the thermal performance and also to identify and evaluate the relative severity of heat-related problems. Recent innovations in detector technology and incorporation of built-in visual imaging & infrared software solutions etc. have resulted in advent of more cost-effective thermal analysis solutions (2).

Infrared thermography is the only diagnostic technique that allows instant visualization and verification of thermal performance. This helps the maintenance personnel to examining anomalies, quantify it with precise non-contact temperature measurement and document easily with professional easy-to-create infrared reports (3).

Infrared thermography is, therefore, a proven effective, preventive maintenance (PM) technique that quickly, accurately and safely locates problems prior to failure indicated by thermal anomalies. The case studies reported have indicated four-to-one return for every rupee spent on infrared inspection on account of identification of potential component failures and by preventing the much higher costs associated with manufacturing downtime, production losses, fires and catastrophic failures (4). Improvements in thermography have created practical applications in diverse areas such as:

- Loss control applications (for example, in recreational maritime vehicles)
- Home and building inspections
- Security
- Healthcare
- Business
- Industry (e.g., the chemical industry)
- Environmental hazard detection
- Visual enhancement for equipment operators and for night use

Integrating Thermography With Preventive Maintenance

Infrared thermography cameras can be used as the first line of defense in a preventive maintenance program without disrupting operations. Thermography preventive maintenance program requires continuous monitoring and analysis of the data collected over a period of time. Maintenance engineers are required to make

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a route map of the process and equipment in their plant and to store IR thermographic data in a computer system for all equipment and processes. The generated IR therographic data base can be used to evaluate the thermal history of the equipments and to initiate corrective action accordingly.

In case the temperature observed in equipment is markedly different from previous readings, the maintenance personnel should use other maintenance technologies, such as vibration monitoring, motor circuit analysis, airborne ultrasound, and lube oil analysis to investigate the source of the problem and determine the next course of action. For best results from IR thermography as a preventive maintenance tool, it is suggested that data from all other maintenance practices used in the mill may also be integrated into the same computer system, so that they share the same equipment lists, histories, reports and work orders. Once the infrared data is correlated with data from other technologies, the actual operating condition of all equipment can be reported in an integrated format.

Inspection Process

Following inspection process may be adopted for IR Thermography analysis.

1. Begin by using existing lists of equipment from a computer managed maintenance system (CMMS) or other inventory tool.
2. Eliminate equipment or processes that are not well suited for infrared measurement
3. Review maintenance and production records. Prioritize key equipments that are prone to failure or often cause production bottlenecks.
4. Use a database or spreadsheet to group the critical equipment together, either by process area or functions, into separate inspection blocks. Inspection should be conducted on a regular frequency for each inspection block depending upon its requirement / failure history.
5. Use the thermal image camera to capture baseline images of each piece of the critical equipment. On same pieces of equipment, multiple thermal images of key components or subsystems may be captured after inspection of its thermal images.
6. Download the baseline images into the computer system, which will be used to document location descriptions, inspection notes, emissivity and Reflected Temperature Compensation (RTC) levels and alarm levels if appropriate.
7. During the next inspection collect the desired information and store it in the system to create a database of the equipment's thermal image history. Many thermal image cameras support uploading the previous inspection images onto the camera and follow the onscreen prompts to find out prompt thermal analysis reports.

Table 1 shows the sample array of equipment on the Thermal imaging program for a pulp and paper mill.

Table - 1

Preventive Maintenance Type	Program
Thermal imaging-regular inspection	All Transformers
	All switch gears
	All motor control panels of the pumps
	All MCB Panels
	All Variable frequency drives
	All Process Panels
	All sites for thermal Insulation inspection
	Vacuum pump panels
	Compressor panels etc.
On demand Inspection	Pumps and gears drives (on demand)
	Electrical motors (on demand)
	On demand inspection of any other equipment/processes

IR Thermographic Case Studies For Preventive Maintenance and Energy Conservation Assessemnt

IR Thermography due to its ease of operation and generation of valuable thermal data for various equipment, distribution systems, pipes & storage tanks and process operations etc., is being used as a preventive maintenance technique in various process industries. In pulp and paper mills this technique can be used effectively to monitor electrical & thermal systems and manufacturing processes, to identify any deviation in their respective thermal characteristics. In this section case studies conducted in pulp and paper mills on IR Thermography of electrical, thermal and process systems are presented. The IR Thermography data has been used to identify energy saving opportunities in the mill.

(I) IR Thermography of Electrical Systems

It has been observed that the untimely shutdown of electrical distribution equipment and motors etc., often results in lost production, higher operating costs, and loss of profits. The studies conducted at mills have shown that in integrated and non-integrated paper mills over 30%of their total losses results from electrical problems.

IR Thermography as a preventive maintenance technique offers method to identify the commencement of the problem in the equipment and thus may save expensive maintenance.

Conductor terminations and connections

A high percentage of problems occur in terminations and connections, particularly in copper-to-aluminum connections. They show up as hot spots. As a thumb-rule, a splice connector should not be warmer than its conductors, in case it has been sized properly and is working perfectly. However, in practice the connectors are mostly hot and unnoticed, thereby causing frequent untimely failures in the system. Table-2 below shows the maximum temperature recorded in various panels, connectors, starters etc in a pulp and paper mill during the IR thermographic inspection. These are un-noticed till some problem erupts in the plant.

The high temperatures recorded above are mainly due to loose connections. The IR Thermographs for most of the above connections are shown in Fig 1. During the investigation it was

Table-2. List of temperatures recorded in various connectors in pulp and paper mill.

S No.	Bus bar/ connectors	Locations	Motor Details				Connector surface Temp., °C		Observations
			Rated kW	Voltage, V	Power Factor	Amp	Min.	Max.	
1	Vacuum pumps bus bar	PM 3	250	440	0.95	345	36.5	70.1	faulty connectors (loose wiring)
2	400 HP Pump 1	PM 2	298.4	440	0.95	412	33.9	110	faulty connectors (loose wiring)
3	500 HP pump 5	PM 2	373	440	0.95	515	36.1	98.3	loose wiring or over tightening of bolts
4	Pulper connectors	PM 4	186.5	440	0.95	258	35.6	70.1	Do
5	Poir Pump connectors	PM 3	74.6	440	0.95	103	35.6	110	Do
		PM 3	74.6	440	0.95	103	34.6	96.5	Do
6	Pulper 1 connectors	PM 1	149.2	440	0.95	206	33.8	65.3	Do
7	Poir pump connectors	PM 1	74.6	440	0.95	103	37.7	90.2	Do
8	ID Fan 1 connectors	Power House	186.5	440	0.95	258	32.4	71.3	Do
9	Feed Pump 1 connectors	Power House	111.9	440	0.95	155	38.6	110	Do
10	Vacuum Pump connectors	PM 2	186.5	440	0.95	258	33.1	76.4	Do

revealed that the hot spots due to loose connections are responsible for min. 0.1 Ohm resistance to ground and it results in power loss to the ground. The analysis of power loss to the ground is presented in Table -3. The calculations for power lost to ground are presented in Annexure-I.

Case Study

(i) Power lost to ground from hot spots in the connectors
Assumption–

Hot spot due to loose connection is responsible for 0.1 Ohm resistance to ground.

Motor details- 300 kW , 440V, 414 Amp

Power lost to ground
= (amperage)^2 x resistance
= (414 amp)^2 x 0.1 Ohm
=17.1 kW

(ii) Winding losses due to heating

Motor details 300 kW, 440 V, 414 Amp, PF 0.95

Surface temperature of motor Min. 45°C, Max. 110°C

Temperature Dependence of Resistance is calculated as
$R_t = R_0(1 + C_1T + C_2T^2)$ for temperature lying between 0°C to 850 °C

Where; $C_1 = 3.9083 \times 10^{-3}$ / °C
$C_2 = -5.775 \times 10^{-7}$ / °C
R_o = Resistance at 0°C (Ohm) = 0.889
T = Hot surface temperature, °C= 110 °C

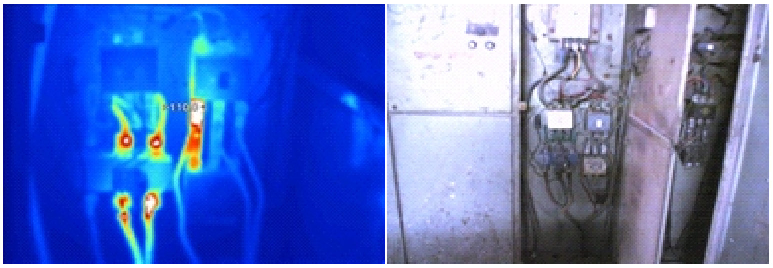
Therefore;

$R_t = 0.889 [1+(3.9083 \times 10^{-3} \times 110) + (-5.775 \times 10^{-7} \times (110)^2)]$
= 1.271 ohm

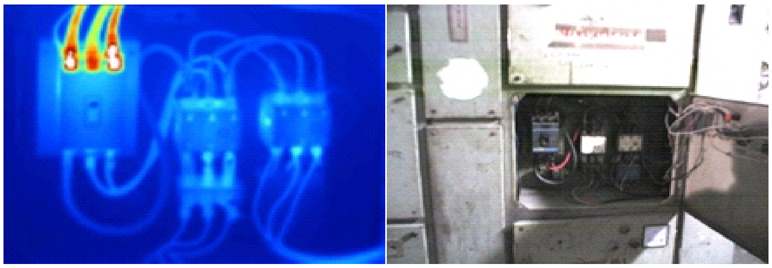
$R_t - R_0$ = 1.27 0.889 = 0.381

Winding losses due to temperature rise = $I^2 \times R$
= $(414)^2 \times (0.381)$
= 65.3 kW

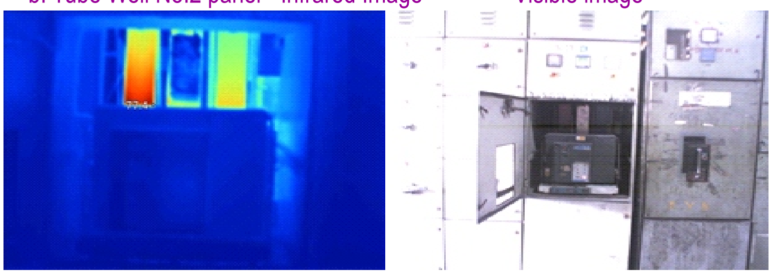
Fig.-1: IR Thermographs of the connectors at various locations in pulp and paper mill



a. Deinking chest Pump panel - Infrared Image Visible image



b. Tube Well No.2 panel- Infrared Image Visible image



c. Turbine main panel - Infrared Image Visible image

Table 3 Assessment of power lost to ground in various hot spots in the connectors

S.No	Bus bar/ connectors	Locations	Connector surface Temp., °C Min	Max.	Hot spot resistance to ground, Ohm	Power lost to gound, kW
1	Vaccum pump bus bar	PM 3	36.5	70.1		11.9
2	400 HP Pump 1	PM 2	33.9	110		17.0
3	500 HP Pump 5	PM 2	36.1	98.3		26.5
4	Pulper connectors	PM 4	35.6	70.1		6.6
5	Poir Pump Connectors	PM 3	35.6	110	0.1 Ohm	1.1
		PM 3	34.6	96.5		1.1
6	Pulper 1 Connector	PM 1	33.8	65.3		4.2
7	Poir pump connector	PM 1	37.7	90.2		1.1
8	ID Fan 1 connectors	Power House	32.4	71.3		6.6
9	Feed Pump 1 connectors	Power House	38.6	110		2.4
10	Vacuum Pump Connectors	PM 2	33.1	76.4		6.6
11	Vacuum Pump Connectors	PM 1	34.3	110		6.6
12	Vacuum Pump	PM 3	36.5	70.1		9.6
13	De Inking Chest Pump	PM 3	35.0	110		0.2

Total savings = 101.5 kW

Annual Savings:

kWh savings per annum = 101.5 x 8000 hrs = 8,12,000 kWh

Monetary saving per annum @ Rs. 5.00 per kWh

= 8,12,000 x 5.00 = Rs 40.60 lakhs

IR Thermography of Electrical Motors

IR Thermography of an operating motor can show the surface temperature of the motor without any contact and disturbing the process. Rise in surface temperature of the motor can show abnormality in its functioning. The IR Thermograph can show the area where heating is taking place and corrective action can thus be initiated. In most of the case studies using IR Thermography, it has been observed that hot spots are mainly seen in case of faulty coupling or in the motor binding.

Heat produced in the motor electrical systems can result in significant undesirable energy losses. The variation in the operating temperature of metal of the winding results in the variation of resistance. This variation in resistance was given by Calendar- van Deusen relation (5, 6)

$$R_T = R_0\,[1+C_1T+C_2T^2+C_3T^3\,(T-100)] \text{ for } (-200^0C < T < 0^0C)$$

Where R_T is the resistance at temperature T, and R_0 is the resistance at 0°C. Since most of the equipment working in plant as above 0°C we can use equation.

$$R_T = R_0\,([1+C_1T+C_2T^2) \text{ for } (0^0 < T < 850^0C)$$

Where C_1= 3.9083 x $10^{-3}/^0C$, C_2 = -5.775x$10^{-7}/\,^0C^2$ &C_3 = -4.183 x $10^{-12}/\,^0C^4$

Winder loss is the term often used to predict losses due to heat produced in the conductors of bindings or other electrical devices. It is also referred to as I^2Rt and states that the energy lost each second, increases as the square of the current through the windings in proportion to the electrical resistance of the conductors.

Table-4 below shows the surface temperatures recorded for various motors in a paper mill. Analysis of winder loss is presented in Table-5 for above motors. Fig. 2 presents the IR Thermographic image of a motor showing its temperature profile.

(II) IR Thermography for steam and condensate system Inspection

IR Thermography is very useful non-contact technique to find out surface temperature of hot steam and condensate pipe lines as it can be used from long distance (upto three meters) to monitor the surface temperature of inaccessible locations. The maintenance department can study steam systems and find out energy savings within following areas.

Table - 4. List of temperatures recorded in various motors in pulp and paper mill.

S. No.	Motor Details						IR Thermography details	
	Motor No.	Location kW	Rated V	Voltage, Amp	Current	PF	Minimum Surface Temp, °C	Maximum Surface Temp, °C
1	120 hp Motor	PM-I Ist Press	90	430	130	0.93	45	110
2	150 hp Motor	PM-I, IIIrd Press	110	435	155	0.94	43	105
3	150 hp Motor	PM-I refiner	110	440	151	0.96	46	110
4	150 hp Motor	PM-I Vacuum Pump	110	440	151	0.96	42	100
5	120 hp Motor	PM-2, Turbo	90	439	125	0.95	40	98
6	350 hp Motor	PM-2, Refiner	260	440	349	0.98	45	80

Table- 5 Assessment of winding losses in various motors.

S. No.	Motor Details		IR Thermography details		Resistance at Max	Winding Losses due to Temp.
	Motor No.	Location	Minimum Surface Temp, °C	Maximum Surface Temp, °C	Temp., Ohm	rise, kW
1	120 hp Motor	PM-I Ist Press	45	110	2.48	26.9
2	150 hp Motor	PM-I, IIIrd Press	43	105	2.41	36.7
3	150 hp Motor	PM-I refiner	46	110	2.48	36.0
4	150 hp Motor	PM-I Vacuum Pump	42	100	2.34	32.8
5	120 hp Motor	PM-2, Turbo	40	98	2.31	22.1
6	350 hp Motor	PM-2, Refiner	46	112	2.05	141.5

Total savings, kW 295.9 kW

Annual Savings:

kWh savings per annum = 295.9 x 8000 hrs = 23,67,200 kWh

Monetary saving per annum @ Rs. 5.00 per kWh

= 23,67,200 x 5.00 = Rs 118.36 lakhs

Fig.-2: IR Thermographs of a motor and shaft in a pulp and paper mill

Motor   Shaft

1. Leak detection and elimination
2. Steam and condensate pipe line insulation checks.

The case studies of thermographic temperature measurements in various locations in pulp and paper mill are presented in Table- 6

showing the high surface temperatures. The surface temperature data can be used to assess the heat loss from the hot surfaces to justify insulation of the hot surfaces.

(III) IR Thermography for process monitoring

Various options can be explored to utilize IR Thermography for process monitoring in a pulp and paper mill depending on requirement. We have made an attempt to utilize IR thermography in some of the process operations during our studies. The areas where this technique can be useful are listed below.

1. Study of temperature profile of paper on pope reel to find out heating drier temperature uniformity.
2. IR thermography study on sediment deposits in various storage tanks showing deposits as cool area in the bottom of the tank.
3. Checking of storage tank level by using IR thermography.
4. IR thermography study of pipe lines in stock preparation and causticization section to find out sedimentation inside the pipe lines. The sedimentation inside the pipe line can be seen as cold spots.
5. Study of heat exchanger tube blockage.
6. IR thermographic study of surface temperatures of lime kiln shell to find out refractory line condition. The hot spots on the surface of lime kiln show damage in the refractory lining.

The IR thermographic images of the above processes are shown in Fig. 3 to indicate effectiveness of the technique as a preventive maintenance method for monitoring process operations in pulp and paper mills.

Conclusions

Thermography is a useful tool for preventive maintenance applications without hampering the operations. Further

Table 6. Temperatures recorded in various steam pipe lines and assessment of energy saving potential in pulp and paper mill

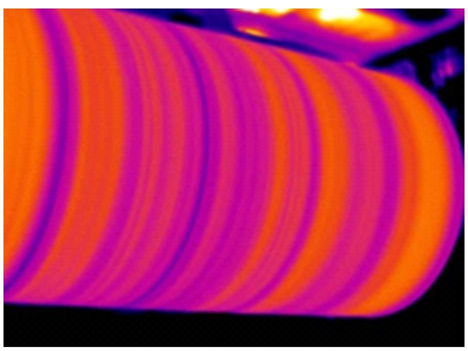
Description	Length of the pipe (m)	Pipe dia. (mm)	Surface Temp (°C)	Total quantity of steam saved (t/a)	Total cost of steam saved (Rs.)	Insulation cost (Rs.)	Simple payback period (month)
Steam line from main header to The mocompressor	10	203	131	100	82089	21025	3
Steam line from header of post dryer	29	127	128	276	227417	60974	3
Steam line from header to pre dryer	40	203	128	380	313679	84102	3
Steam line from header to MG cylinder	40	203	128	380	313679	84102	3
Condensate line from Condensate Tank to Boiler	200	127	117	986	813258	276948	

thermographic analysis can lead to following benefits in a pulp and paper mill.

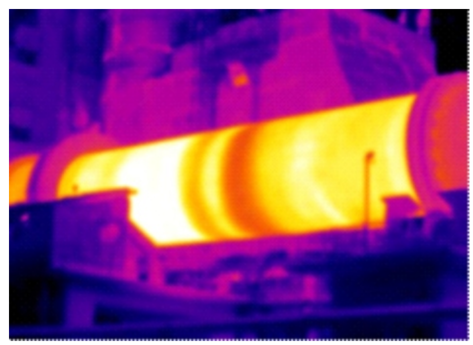
- Extended equipment life
- Reduction in plant downtime
- Improvement in plant reliability
- Maintenance can be scheduled for the most convenient time

Analysis of thermal data collected from various electrical distribution systems, motors, pumps, transformers, vacuum pumps, steam and condensate pipe lines and process equipment etc., can be useful to find out energy saving potential by initiating timely corrective actions. Thus IR Thermography as a preventive maintenance technique, can also support in energy conservation activities of the mill.

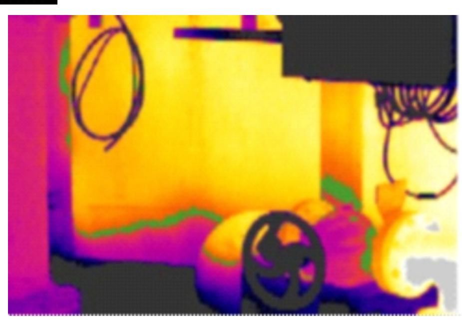
Fig.3 IR Thermographs of paper roll and some processes in a pulp and paper mill



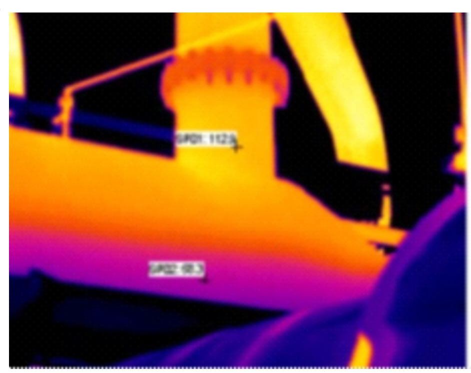
A. Temperature profile of paper roll on pope reel



B Temperature profile of lime kiln



C. IR Thermograph of a tank in chemical recovery section



D. IR Thermograph showing sedimentation in transfer pipe lines.

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