
Predictive Maintenance and Energy Savings in Vaccine Manufacturing

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ABSTRACT

Biological manufacturing is an intricate process requiring a variety of utility inputs. The Bio-Technology Manufacturing Complex at Merck is a cutting edge facility designed as an almost fully stand-alone building with most of its utilities processed internally. WFI, clean steam, emergency/peak shave power, UPS, compressed air, chilled and hot glycol are all stand-alone systems within the building. There is also a full complement of air handlers for clean room air quality control for Class 100 through Class 10,000 air. Plant steam and electric are the only utilities brought in from external sources. With the long processing times for batches of vaccines, extremely high market value and even tighter quality control measures, failure of any piece of utilities or processing equipment is unacceptable. To further complicate troubleshooting efforts, vessel integrity cannot be broken at anytime during the processing of a lot. The need for non-intrusive means of equipment examination is critical in this challenging maintenance environment. We have recently made significant improvements to our predictive maintenance (PdM) program through the addition of an extensive thermal imaging program.

We once inspected most all of our equipment in a static state, but infrared (IR) thermal imaging has allowed us to view everything in a dynamic state—the state in which all prior failures had occurred. This paper details the use of thermal imaging to evaluate power distribution equipment and determine whether or not maintenance is required. With much of our equipment running 24 hours a day, and the revalidation required if the equipment were taken down, much of our power distribution equipment was ignored from the PdM perspective. Thermal imaging has allowed us to evaluate this equipment while in operation so only required shutdowns must be taken. As an added benefit, the corrective measures we are taking as a result of thermal audits have contributed to a significant energy savings for the building. Details of some of the measures we have taken and the resulting energy savings are presented in this paper.

Keywords: Biological manufacturing, predictive maintenance, preventive maintenance, utilities, non-intrusive, IR thermography.

INTRODUCTION

The primary focus of any maintenance program is to insure equipment reliability during operation. Equipment downtime for any reason is costly to a company, but this cost is multiplied several times over if the downtime is due to failure during a production run. Scheduled maintenance downtime is the only way to avoid running equipment to failure. How does one prioritize maintenance so that only those things requiring attention are taken out of service between production runs? Thermal imaging has become a principal means of determining when pieces of equipment are taken down for repair. The principal area of discussion for this paper will be maintenance of electrical power distribution equipment (motor control centers (MCCs), disconnects).

ELECTRICAL SYSTEMS – WHAT MEGGERING AND AMP DRAW CAN'T TELL YOU!

Our manufacturing facility has several hundred electric motor starter buckets and variable frequency drive buckets. Preventive maintenance on this equipment has in the past consisted of purely static checks. In a startling number of cases the electrical equipment was not inspected at all! The general procedure goes something like this: A PM for a piece of equipment is generated based on its assigned maintenance frequency. When the inspection comes due, the equipment must first be taken out of service after a production lot is completed. Lock out/tag out procedures are followed, and the equipment is examined in a static state. This involves tightening connections, resistance checks, contact inspections, and other

inspections of the inside of the bucket and disconnects. Upon completion of these static checks, the lock out is removed. Often, the equipment will be run and current readings taken as the last step of the inspection before returning the equipment to production.

The principal downfall of this system is that there is no conditional check or dynamic inspection used to determine when equipment should be maintained. The entire system is time-driven, based on suggestions in manufacturer's literature. For simple cleaning tasks that do not require shutting down the equipment, time-based measures make a great deal of sense. Complete electrical bucket maintenance involves changing pitted contacts and relays, tightening all connections; replacing overloads and visually inspecting circuit board solder connections. To complicate the matter, there are many pieces of equipment in the biological manufacturing setting that are required to run constantly to maintain an aseptic environment for vaccine processing. Taking this equipment down for an inspection has the added cost of requiring a complete decontamination of the entire processing area affected by the shutdown once the equipment is restored to service. This is the predominant reason why so much equipment was found to be not maintained at all. Time-driven maintenance does not provide the most cost-effective solution to keeping equipment in top running condition in this type of setting. Condition based maintenance—where dynamic inspection gives distinct clues about the condition of the electrical components—is a far better means of determining what equipment needs to be maintained.

Enter infrared thermography! Why is IR thermography an effective tool for determining when electrical equipment is in need of maintenance? Temperature is a principal indication of trouble when examining electrical equipment. Heat is generated as a result of current flowing through a circuit. Careful planning is always required when installing drives and starters to insure proper alignment and spacing to insure that large temperature rises do not occur. When electrical connections heat up, they become less effective at transmitting current to the driven equipment. High temperatures also negatively impact microelectronics within drive controllers. High temperature at connection points is a distinct indicator of loose or fouled connections. Likewise, a high temperature on a set of contactors indicates an improper connection due either to contact pitting or lack of spring tension. High temperatures on a drive circuit board can indicate a loose solder joint or other connection problem on the circuit board. A quick shot of an electrical bucket with an IR camera will quickly show any and all of these problems without requiring equipment shutdown. Over the course of a few shifts, our electricians can conduct an infrared survey of every electrical starter bucket in our facility. The data are then reviewed with IR software to determine which buckets need attention. Shutdowns of the selected equipment can then be planned with production for only those items requiring attention.

The introduction of infrared thermography to our facility has allowed us to shift our standard operating procedure from one of time-driven preventive maintenance, to one of condition-based predictive maintenance. The costs of taking down equipment that does not need maintenance can then be avoided altogether. At Merck we have now put every piece of electrical equipment on a maintenance plan to be inspected with the thermal camera at regular intervals. Maintenance can then be performed on only those items requiring attention, and we can be sure that all equipment is being serviced when it needs to be because we are constantly looking for defects. As we progress in this system, we can free up more time for our maintenance personnel to support capital improvement projects. These jobs are generally contracted out due to the lack of time for our own staff to perform the work. Predictive maintenance with IR thermography is opening up more opportunities for our own mechanic to do capital work, saving the company the added cost of contracting the work out.

On a safety note, surveys with infrared cameras may also reveal equipment that is so far deteriorated that catastrophic failure may be imminent. Take a look at Figure 1.

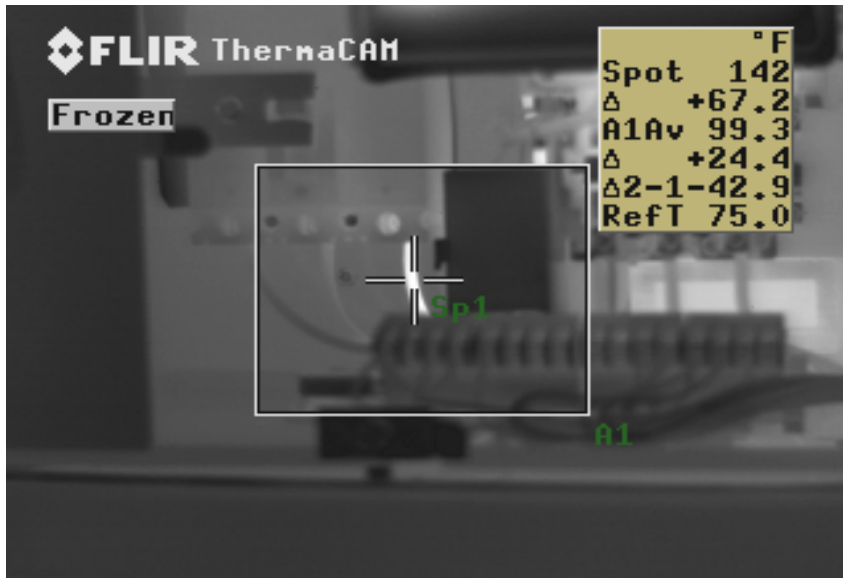


Figure 1. Thermal Image of line side lugs of air handler starter.

Figure 1 shows an MCC bucket imaged during a routine infrared camera scan. One of the line side lugs showed severe overheating. We immediately contacted the appropriate production area and shut down this piece of equipment. Upon inspecting the starter, the lug that was supposed to be holding the red hot wire in place had completely fallen apart. This wire was merely laying inside of the connection point. We stripped some of the insulation back to see if we could simply trim the bad wire off the end and use the rest. We discovered that this wire and insulation was damaged for over 18 inches from the connection point. The insulation for the first six inches had started to melt and bubble. It was only a matter of time before this particular bucket arced and potentially exploded, causing severe equipment damage and potentially serious injury. Here is what the bucket looked like after running new wire and fixing the lug:

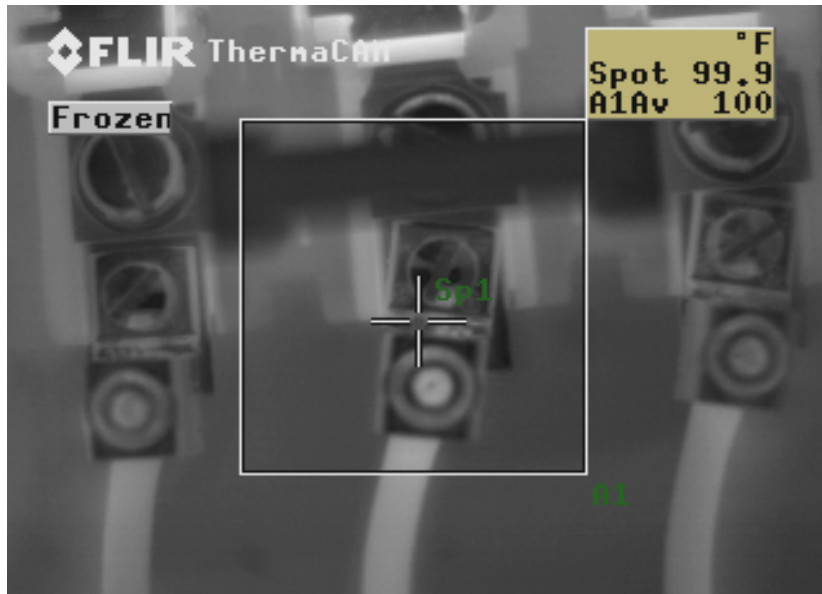


Figure 2. Infrared thermal image of airhandler lugs after repair.

RESULTS

The beauty of infrared surveys of electrical equipment is two-fold. First, all equipment need only be viewed at the starter bucket in the MCC section. Problems in motors or disconnects downstream from the MCC will manifest themselves as a temperature rise all the way back along the power feeds. We ran into several cases where the temperature difference in the MCC bucket was due to faulty springs in a downstream disconnect. Second, with only a thermal image and a current reading you have all the data you need both to make a determination if the equipment needs to be serviced and to calculate the approximate energy loss you are suffering. Resistance in metals changes in a linear fashion with temperature change. The equation describing this phenomenon is:

$$\Delta R = R_0 \alpha \Delta T$$

As the temperature rises, the resistance rises. Power consumption is directly proportional to resistance as described by:

$$P = I^2 R$$

Thus, the increased power usage due to a rise in temperature of electrical components is:

$$\Delta P = I^2 R_0 \alpha \Delta T$$

The theory sounds great, but how does it hold up? After completion of the thermal audits and identification of all the equipment that required attention, we scheduled maintenance on all of the buckets over the course of several months. The following is a bar graph showing the daily original power consumption, theoretical improvement and actual measured improvement.

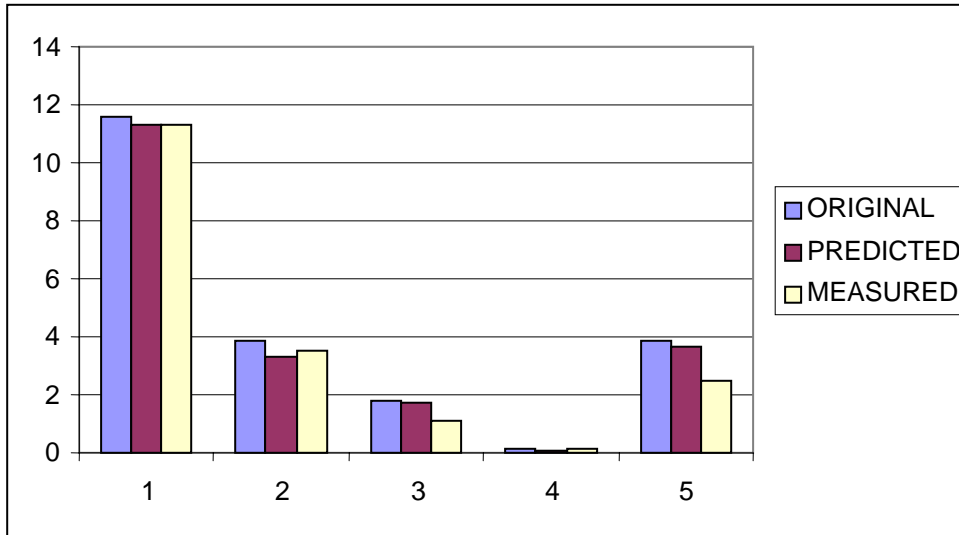


Figure 3. Comparison of predicted energy savings to measured savings.

The annualized saving we have realized thus far amounts to 969.44 MW-hrs, or an 8.36% reduction in our overall usage. This translates into a real, annual monetary savings of \$75,616 at the going energy rate provided by our utility.

We have now put all of our electric equipment into the maintenance system. Going forward, we will begin auditing our MCCs on a six-month frequency. For the equipment that was never put into the PM system, we now have an ongoing dynamic check to tell us when maintenance is required. For those items that have time-based inspections in our CMMS, we can now begin extending the frequencies or even making the inspections completely determined by our condition based thermal audits. The vaccine industry is heavily regulated by CGMP (current good manufacturing practice) so the process of changing procedures that are already in the system is time consuming, but we have laid the ground work to make a very good argument to our quality and regulatory groups. As we improve our equipment and drive down loss, we free up our maintenance staff to work on capital improvement projects, which are now contracted to outside labor due to the heavy maintenance load. All of this has a direct and positive impact on the company's bottom line.

SUMMARY

It is certainly not news to anyone that every company must continually strive to reduce the costs required running their business. Infrared thermal imaging cameras provides a powerful tool for maintenance personnel to utilize to insure that the right equipment is being serviced at the right time. They allow for real-time analysis of the operating system so that judgment can be made on equipment health in the dynamic state. The information provided will allow maintenance crews to move away from time-driven maintenance toward condition-driven maintenance. Labor can then be utilized to perform capital projects that would have previously required contract labor to complete. Potential failure conditions can be spotted quickly so that failure related shutdowns and their associated costs can be avoided. All of these items will have a direct, positive impact on a company's bottom line. In just six months time, we have managed to save enough energy to more than pay for the camera, software and training time required to set up a thermal imaging program.

Thermography has applications beyond electrical work as well. We have begun evaluating heat exchangers and doing scheduled passivations based on a comparison between the actual temperature differentials, and the expected differentials based on manufacturer specifications. The passivation

process is somewhat costly and very hard to justify without real numbers. The first heat exchanger we evaluated was operating at about 10% of the manufacturer's specified temperature spread. After passivation, the heat exchanger is now at 92% of the specification! The wasted WFI (water for injection) from just one batch out of this exchanger more than covered the price of the passivation. The application possibilities in any manufacturing setting are boundless, and well worth the effort it takes to set up the program.

REFERENCES

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