The Benefits Of Applying Reliability-centered Maintenance On New Assets

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Introduction

In this article I will draw on my experiences in conducting RCM analyses for Dofasco Inc., a large North American steel manufacturer with over $5 billion in capital assets. The majority of the RCM analyses that had been conducted at Dofasco had been on older existing assets. The nitrogen compressor plant cooling tower is an example of the application of RCM to a new asset. When carrying out an analysis on a new asset some specific benefits to be realized are:

• Development of a base maintenance program - Key maintenance tasks are identified and implemented during commissioning and the early stages of start up. Critical tasks are identified that would otherwise be missed.

• Protective Devices - The appropriate failure finding tasks will be set up for each protective device before the equipment starts up. It ensures that each protective device is tested during commissioning before the equipment is started up.

• In depth knowledge gained about the equipment - Commissioning time can be reduced. Ramp up time to full operation can be reduced. Equipment operating practices can be identified during start up and from this the necessary operating and maintenance procedures can be developed. Performance standards for the equipment (maintenance costs, required up time, etc) can be developed during start up. Key performance variables for the equipment can be developed during start up. The potential to reduce failures resulting in "infant mortality"

Nitrogen Compressor Plant Cooling Tower

This new counter-flow tower replaces two 30-year-old cross-flow towers that have since been torn down.

The main purpose of this new cooling tower is to cool the service water used on the nitrogen plant compressors and #4 ASU scrubbers from a maximum temperature of 100°F down to 82°F or lower. Within the nitrogen plant there are two compressor systems. The 45 PSI Centac nitrogen compressors supply 12 PSI purge nitrogen to the blast furnaces, steel making and the coke plants. Loss of this nitrogen supply would have severe safety consequences. For that reason, the nitrogen supply would be manually switched to an alternate offsite source when the cooling water temperature reaches 85°F. This would significantly increase the cost for supplying low pressure nitrogen.

The 500 PSI Bellis and Morcom and Ingersol Rand nitrogen compressors feed nitrogen to the steelmaking KOBM process as an inert gas to stir the contents of the furnace as the steel is being made. Loss of this nitrogen supply has the potential of shutting down the steelmaking process, which would result in costly production losses. Sufficient nitrogen cannot be fed from the off site source as an alternate supply to the 500 PSI compressor.

The main components of the cooling tower system area are as follows:
• hotwell sump and pumps
• system piping
• two cell counter flow cooling tower
• cooling tower fans and drive systems
• cooling tower fan motors with variable speed drives
• chemical treatment system
• fire protection system

Hotwell Sump And Pumps

The purpose of the cooling tower hotwell is to store the hot service water (100°F) that is fed to the cooling tower. Located in the hotwell sump are three hotwell sump pumps. The pumps are designated as duty, trim and standby. These vertical pumps have a capacity of 2000 USGPM per pump and are driven by 60 HP motors. The operation of the pumps is controlled by a bubbler type level control system. The main functions of this system are to prevent the sump from overflowing, to prevent the sump from running dry and to prevent the pumps from cycling on and off.

System Piping

The hotwell pumps transfer the hot clean water from the hotwell, through the carbon steel interconnecting piping to the feed water inlet at the cooling tower. The feed water supply to the distribution header system is controlled to a maximum pressure of 2.4 psi by a standpipe vent.

Counter-Flow Cooling Tower

This is a two-cell counterflow cooling tower fabricated from California redwood with stainless steel fasteners. The water distribution header system, which is located at the top of the tower just below the fan deck, is fabricated from PVC piping. The distribution system is made up of a series of piping headers, with nozzles along the bottom of each header, to distribute the water evenly over the honeycomb film type fill. As the water passes through the fill a thin film of water is formed which maximizes the area which will come in contact with the cooling air. The cooled water (82°F) then falls into the cold-water sump at the bottom of the tower.

Cooling Tower Fans And Drive System

The counter flow ambient air, used to cool the hot water falling through the tower, is drawn into the bottom of the tower via two ten foot diameter, five blade fibreglass fans with a variable pitch which can be manually adjusted. The fans are enclosed in a fibreglass stack, which helps to induce the require draft inside the tower and prevents access to the rotating fan blades.

Each fan is driven by a 40 HP totally enclosed, fan cooled, premium efficiency, severe duty motor. The power to each of the two motors is fed through a variable speed drive. In the auto mode the speed is automatically varied based on the cold well sump water temperature. As the temperature in the coldwell increases, the fan speed is increased and as the temperature decreases, the fan speed is reduced. The fan motor direction can also be reversed, to prevent or eliminate icing inside the cooling tower in the winter months.

The operator, based on the amount of ice build up inside the tower, can only reverse the motors manually. If either one or both of the variable speed drives fails, the power to the motors can be fed from the conventional starters at a constant speed of 1800 RPM in either the forward or reverse direction through a three position transfer switch. A vibration switch is also mounted on each motor housing which will automatically shutdown the motors on high vibration.

Chemical Treatment System

The chemical feed system for the tower is in place to control corrosion, scale and microbiological activity in the bulk water. Sodium hypochlorite 12% is fed into the bulk water to control microbiological activity. An oxidation reduction potential system is used to automatically control the sodium hypochlorite feed rate by measuring the milli-volt potential in the water. To control scale and corrosion, a scale and corrosion inhibitor is fed into the bulk water. This product is fed in at a very low continuous rate which is manually adjusted based on four water samples collected and analysed each day for phosphate levels by the plant operator. The scale level is also mechanically controlled by blowing down a portion of the bulk water to sewer based on the conductivity of the water. Corrosion coupons are also installed in the bulk water and are removed and analysed every 90 days.

Fire Protection System

This cooling tower has a deluge type fire protection system, which is fed by city water. In the event of a fire an alarm is sent to the Fire Dept and the cooling tower fan motors are shutdown.

Performance Targets For The RCM Analysis

1) Establish a base maintenance program for the new nitrogen plant cooling tower.

2) Minimize the potential for shutting down the low pressure (45 PSI) nitrogen compressors.

3) Minimize the potential for shutting down the high pressure nitrogen compressors, which could shutdown the steelmaking process incurring significant operational consequences.

Analysis Description

Kick Off Meeting

Once the preparation package for this analysis was complete a meeting was set up with the review team member to start the analysis. In addition to all of the review team members being present, the area operations and maintenance coaches were also present as well as the operations/maintenance manager.

The purpose of this meeting is two fold. First, the manager has an opportunity to communicate first hand, that he supports conducting an RCM analysis on this asset and that the resource requirements will be made available to ensure that it will be completed and implemented. Second, the operating context and performance targets are reviewed with the team so that they clearly understand the boundaries the analysis will cover and why the analysis is being done based on the performance targets for this analysis.

Review Team Members

Dofasco
- Mechanical Rep (Implementation Manager)
- Instrumentation Rep
- Electrical Rep
- Operations Rep

Vendors
- two representatives from the company that designed and built the cooling tower
- two representatives from the company that supplied and built the variable speed drives
- one representative from the company that supplies the treatment chemicals

Review Meetings

The review meetings were run every weekday for four hours each morning until the analysis was complete. This analysis was estimated to require seven meetings, but actually took nine. The maintenance representatives continued with their regular duties in the afternoon, while the operations representative, who was removed from his regular duties, gathered additional information for the analysis in the afternoon.

Analysis Results

Overall Summary

• 30 functions • 33 functional failures • 113 failure modes

Breakdown Of Failure Modes

• 70 have safety consequences • 24 failure modes, which are hidden
• 19 failure modes, which are non-operational

Breakdown Of Maintenance Tasks

• 20 are on-condition • 2 are scheduled restoration
• 2 are scheduled discard • 24 are failure finding
• 14 are no scheduled maintenance

Breakdown Of Redesign Tasks

• Redesign is required
  - 9 are physical redesign
  - 23 are developing new procedures
  - 3 are issuing operating memos outlining the consequences of a given action

• Redesign may be desirable
  - 4 are physical redesign
  - 4 are developing new procedures
  - 1 is issuing an operating memo outlining the consequences of a given action

Significant Findings

Over and above the tasks that were developed for the base maintenance program for this tower, the following significant findings also came to light as a result of doing this analysis:

1) The variable speed drives would vary the speed of the motors from 0 RPM to 1800 RPM based on the temperature of the water. The fan drive angle gearboxes were designed to operate at a minimum speed of 900 RPM. Below a speed of 900 RPM the gearbox internals would receive little or no lubrication.

2) If the pitch angle on the fan blades was set below 12° the fan motors could run at an amperage higher than design for these motors. This could cause random motor shutdowns or could shorten the life of the motors.

3) The cooling tower fans would windmill in the reverse direction when the fan motors are shutdown. When the fan motors were started automatically by the variable speed drive, or manually by the operator, significant damage would be done to the fan driveline system.

4) There was no control room alarm (audible/visual) to indicate the shutdown of either of the variable speed drives. The only indication that either one of the variable speed drives has shutdown is a local alarm light on the front of the variable speed drive panel. The operators would require this control room alarm to determine when to switch to the conventional power feed to get the fan motors going again as soon as possible.

5) There was no high-level alarm circuit for high water level in the coldwell sump. The water level in this sump could rise to the point where it overflows to sewer and the operator would not be aware of this condition. This would cause a severe imbalance in the chemistry of the bulk water in the cooling tower system.

6) The cooling tower fans could be operated in the reverse direction for an indefinite period of time. To prevent ice build up on the fan stack above the fans, which could have both safety and operational consequences, the cooling tower fans must not be run in reverse for any longer than 20 minutes during the de-icing process.

7) During the winter months the variable speed drive would slow the fan motors down to 900 RPM, but will not shutdown the motors if the coldwell temperature is continuing to drop and falls below 55°F. This could significantly increase the amount of ice build up inside the tower.

8) If the fan motors were run in reverse during the winter months, the variable speed drive would vary the speed based on the coldwell temperature. The fan motors should only be run at a constant speed of 900 RPM when operated in reverse to minimize the stress on the fan motor and drive system.

9) The fan motors are tied into the deluge fire protection system such that they will shutdown automatically in the event of a fire on the tower.

Conclusions

A comprehensive base maintenance program was developed for this new cooling tower. This ensured that maintenance tasks, such as checking oil levels and measuring vibration were carried out on the gearboxes and drive motors.

Nitrogen Cooling Tower RCM Analysis Summary of Significant Findings

Findings	Consequences	Action
The variable speed drives would operate the fan motors at less than 900 RPM in the forward direction. The fan gearboxes must be operated at a minimum speed of 900 RPM to maintain adequate lubrication inside the gear box.	1) Both gear boxes would seize shutting down both fan motors 2) Low pressure N2 compressors would shutdown - feed would be switched to alternate offsite source. 3) High pressure N2 compressors would be shutdown. This would also shutdown the Steel making operation. 4) Cost to replace gear boxes - $12,000	Modifications were made to the variable speed drive to ensure that the fan speed would not drop below 900 RPM in the forward direction.
The variable speed drives would operate the fan motors at less than 900 RPM in the reverse direction. The fan gearboxes must be operated at a speed of 900 RPM in reverse to maintain adequate lubrication inside the gearbox and to optimise the amount of air pulled back down into the tower for de-icing.	1) Both gear boxes would seize shutting down both fan motors 2) Low pressure N2 compressors would shutdown - feed would be switched to alternate offsite source. 3) High pressure N2 compressors would be shutdown. This would also shutdown the steelmaking operation. 4) Cost to replace gear boxes - $12,000 5) De-icing of the tower would not be as effective, which would lead to structural damage.	The variable speed drive supplier modified the variable speed program such that the fan motors run at a constant 900 RPM when in reverse.
The cooling tower fans would windmill in the reverse direction when the fan motors are shutdown. When the fan motors are started automatically by the variable speed drive, significant damage would be done to the fan drive line system.	1) The drive shaft on the fan motor being started would break, damaging the fan blades, fan stack and shutting down the motor. 2) Low pressure N2 compressors would shutdown - feed would be switched to alternate offsite source. 3) High pressure N2 compressors would be shutdown. This would also shutdown the steelmaking operation. 4) Cost to replace the damaged drive shaft, fan blades and fan stack would be $ 8000.	The DC brake was programmed into the variable speed drive program so that the motor will not free wheel when shutdown.
During the winter months the variable speed drive will slow the fan motors down to 900 RPM, but will not shutdown the motors if the coldwell temperature is continuing to drop and falls below 55°F.	Increased icing on the tower, which would lead to significant structural damage.	The variable speed program was modified so that the fan motors will shutdown if the coldwell temperature continues to drop and falls below 55°F.
If switched into reverse for de-icing in the wintertime, the fan motors can be left in this mode indefinitely. The cooling tower fans must not be run in reverse for any longer than 20 minutes at a time to prevent ice build up on the fan stack above the fan.	An excessive amount of ice would build up around the top edge of the fan stack. This ice would break off, striking and breaking one of the fan blades. A section of fan blade would ricochet off the fan stack and fly out the top of the tower onto the ground. This section of fan blade could strike personnel in the area causing serious injury or a fatality.	An alarm and shutdown circuit will be installed on the fan motors to shutdown the fan motors if they are left in reverse for any longer than 20 minutes.

During the commissioning stage a critical vibration shutdown switch was found to be faulty. A new switch was installed immediately. Had this faulty switch not been found it could have lead to significant safety and operational consequences. Failure finding tasks were developed for all of the cooling tower protective devices. Calculations were done to determine the optimum interval for each of the failure finding tasks.

The in-depth knowledge that was gained about this new tower resulted in the following benefits:

• The commissioning time was reduced due to the fact that the commissioning team was able to focus on commissioning this new equipment rather than learning how it works first.

• Ramp up time was reduced due to the fact that there were less equipment failures due to “infant mortality”.

• Critical chemical treatment system operating practices were identified during start up of the cooling tower. These practices were developed into procedures and the required training was carried out for all the operations personnel.

• Key performance standards were developed for the operation of this tower during the winter months.

In addition to the benefits that were realized in each of the above areas a number of significant findings were uncovered as a direct result of carrying out this analysis. If not uncovered and resolved these items would have lead to severe safety and operational consequences with regard to the operation of this tower (Table 1).

It was generally agreed that the key reason these findings came to light is that representatives from the companies that supplied the cooling tower and the variable speed drive were part of the RCM review team. It is also generally agreed that most of these findings would not have come to light, on their own, in time to prevent the respective consequences, had the RCM analysis not been done on this asset. This validates the need to consider doing RCM analyses on the right new assets.

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