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Memorandum

To: Director, Office of Professional and Occupational Regulation

From: John H. Burpee, Chief Boiler/Elevator & Tramway Inspector

Date: November 25, 2015

RE: Technical Report: King Pine Rollback (Sugarloaf Ski Area)

The attached report briefly documents the investigation completed due to the King Pine Rollback that occurred on March 23, 2015.

Following a 2010 chairlift accident, we worked with ski lift owners and operators to focus on developing more comprehensive quality control programs. We asked for an emphasis on upgrading maintenance procedures/program to provide greater detail on how the maintenance procedures are to be completed and ensure all maintenance was completed by trained personnel.

We think Sugarloaf and the other ski areas in the State of Maine have made positive progress enhancing their maintenance program.

The scrutiny of any incident highlights to the many involved that more could have been done to meet expectations. Continuous progress and improvements need to be made to existing maintenance programs.

Technical Report: King Pine Rollback

Executive Summary

On the morning of March 21, 2015 at approximately 11:30 AM, the ski lift known as “King Pine” located at Sugarloaf Ski Area in Carrabassett Valley, Maine was operating with a full load of passengers when it experienced an accident which had 2 elements, a mechanical failure and a rollback.

The initial element was a destructive failure of a coupling in the drive system. After this coupling failure, the lift experienced a rollback of approximately 10 chair lengths or 550 feet. The bullwheel backstop device and the automatic actuation of the emergency brake did not work as intended.

Equipment

The King Pine lift had been in operation during each ski season since installation. The lift has the following demographics:

Registration Number: TA 104

Manufacturer: Borvig Quad Chair Aerial Fixed Grip Tramway

Installed: 1988

Speed: 450 Feet Per Minute (FPM)

Slope Length: 3176 feet with a vertical rise of 1074 feet

As required, the lift had a current valid certificate of operation and was inspected on 10/14/2014.

A full load test was conducted on 10/29/2014 and completed on 11/17/2014.

The drive system has a Kissling VKE340 high speed gearbox and a Kissling V-116 low speed gearbox. The coupling is a splined gear tooth coupling which connects the output shaft of the Kissling VKE 340 high speed gearbox to the low speed torsion shaft of the Kissling V-116 planetary gearbox.

Incident

At approximately 11:30 AM, the King Pine lift experienced a mechanical failure of the coupling that connects the high speed gearbox to the low speed gearbox. Once this failure occurred, the bullwheel became disconnected from the drive system. Once the bullwheel was disconnected from the drive system, its momentum allowed the bullwheel to move forward a short distance before reversing direction due to the load on the lift.

Note: Pictures are in Appendix 1

As the lift slowed and reversed direction, the drop dog/anti-roll back device did not engage the mechanical stops as intended.

Once the lift reversed, the automatic actuation of the emergency brake did not operate as intended.

The speed of the lift continued to increase in the reverse direction until the emergency brake was actuated by a lift operator. As the emergency brakes applied, they gripped the bullwheel flange slowing the rollback and stopping the lift.

Evaluation

Drive System

The drive system failure occurred in the coupling that connects the high speed gearbox to the low speed gearbox. The coupling teeth on the low speed side of the coupling were stripped out of the coupling hub and enmeshed in the matching gear teeth of the low speed torsion shaft (Picture 1 in attachment). The coupling teeth were welded to the low speed torsion shaft by the wash of the metal from the coupling hub surface. The gear tooth surfaces were not welded together on the several teeth that were removed and examined, however, the coupling teeth were worn and distorted.

The low speed torsion shaft appears to have dropped and was rotating on the top of the hollow shaft which drives the bullwheel (Picture 2). There is scoring and deformation on the top of the bullwheel hollow drive shaft where the torsion shaft and coupling were wearing on it.

When the low speed torsion shaft dropped, the coupling was also allowed to drop. There was damage to the bottom side of the coupling (Picture 3).

The coupling had evidence of heating, galling, and loss of material. The coupling rode on the top the bullwheel hollow shaft, causing it to wear. The overall height of the coupling was approximately 5 millimeters less when placed next to a coupling that was believed to be full dimension (Picture 4).

The oil seal was severely damaged (Picture 5) and the bushing (Picture 5) had indications of being heated as well as scoring. There was evidence that the grease used to lubricate the coupling had deteriorated and was essentially gone.

This coupling was installed approximately 4 years ago and was obtained from a maintenance storage area at Sugarloaf. It is not known where the part came from originally and no part number could be seen on the coupling.

The thrust bearing that holds the sun gear in place is located at the bottom of the low speed gearbox. This thrust bearing supports the sun gear which provides vertical positioning and allows for rotation. This thrust bearing has two plates and a rotating element. The rotating element of the thrust bearing was destroyed (Picture 6). Picture 7 shows a rotating element of the thrust bearing in good condition. The plates of the thrust bearing have significant deformation. The plates should be flat with no grooves or indentations (Pictures 8 and 9).

Note: Pictures are in Appendix 1

The bottom of the low speed torsion shaft did not appear to be damaged (Picture 10).

Bullwheel Backstop

During this incident, the bullwheel backstop (drop dog/anti-rollback) device did not properly engage the wedges on the top of the bullwheel. The bullwheel backstop device is supposed to stop the bullwheel soon after a rollback occurs by engaging the drop dog into the mechanical stops (wedges) thereby preventing the bullwheel from rotating more than 30 inches in the wrong direction.

The drop dog (Picture 11) is positioned up by an electrical solenoid. The electrical signal to the solenoid (Picture 12) is controlled by an underspeed switch. At a predetermined speed, the switch allows electricity to energize the solenoid which raises the drop dog. The underspeed switch has a wheel that rotates when the bullwheel rotates (Picture 13). This is how it senses the speed of the bullwheel.

Once the wheel on the underspeed switch is moving at 100 to 200 FPM (the speed of the bullwheel) centrifugal weights move to allow electricity to energize the solenoid which picks up the drop dog. As the speed of the lift decreases to below the set speed, the centrifugal weights no longer allow the solenoid to be energized and gravity causes the drop dog to fall coming in contact with the bullwheel.

The placement of the mechanical stops (wedges) is such that the drop dog rises up to the top of the wedges then drops off the high side of each wedge causing a clunking noise as it moves over each wedge when the lift is moving in the correct direction. If a rollback occurs, the drop dog is supposed to drop once the lift speed decreases to less than the set speed. The drop dog is supposed to come into contact with the high side of the wedge (Picture 14) and stop the bullwheel from rotating.

The underspeed switch energizes the solenoid based on the speed it is sensing regardless of direction of rotation. If the set speed of the switch is 150 FPM, it will energize the solenoid, lifting the drop dog once 150 FPM is sensed whether the lift is going forward or in reverse. The underspeed switch is adjusted by turning the switch clockwise or counterclockwise to energize the solenoid at the desired speed. Once adjusted, the switch setting is “locked” in place by set screws.

The underspeed switch on the King Pine lift had been manipulated and at the time of my inspection was not in the exact position it had been immediately after the accident, so it was not possible to determine its condition, settings etc. The operation of the underspeed switch and drop dog while in place appeared to be moving and releasing the drop dog properly, but there was no way to determine at what speed the drop dog would lift or drop.

The installed underspeed switch was taken to the shop for evaluation. During this evaluation, the operation of the underspeed switch was compared to the operation of a new switch and solenoid. During this evaluation it was noted that the switch would energize the solenoid regardless of which direction the wheel was turning.

Note: Pictures are in Appendix 1

The mechanical stops are steel wedges which are approximately 3/4 inches high on one end and tapered down on the other to allow for the drop dog to ride over it while the lift is moving passengers uphill. The wedges are welded to the top of the bullwheel flange at approximately every 30 inches.

There was an indication (mark) on the top of one of the wedges (Picture 15). The top of the wedge looked like it had been “shaved” off. The top of this wedge had bright metal (not the same color as all the other wedges). It is not known what caused this “skim coat” of material to be removed. No other wedges had any material removed that was attributed to this accident.

Two lift mechanics reported that the drop dog was not completely down on the bullwheel flange immediately after the incident. I noted the drop dog was completely down on the top of the bullwheel flange.

Prior to my arrival, as maintenance personnel were evaluating the incident, the bullwheel inadvertently moved. The bullwheel was made safe by tightening up the emergency brakes so the bullwheel could not move. Unfortunately, the exact condition and location of components were not the same as immediately after the accident.

Automatic Actuation

The bullwheel braking system (emergency brake) was evaluated. The emergency brake is actually three individual brake mechanisms that are only connected by a common hydraulic system. The emergency brakes are held open by hydraulic fluid that is pressurized by a hand pump next to the operating controls.

During normal operation, the brakes are held open by hydraulic pressure. When hydraulic pressure is lost, spring packs force the brakes to close onto the bullwheel flange.   The emergency brakes stop the bullwheel which stops the lift.

The brake linings were new at the beginning of the season. The clamping force of the emergency brake is periodically adjusted to ensure it has enough force to stop the lift within a predetermined distance. The mechanics adjust to the correct holding force by completing a torque test and then ensure the lift has an appropriate stopping distance.

In the event of a rollback, there are mechanical linkages and cables attached to the hydraulic system which are designed to lift a lever and remove pressure from the hydraulic system within a few inches of the lift reversing direction. A mechanical arm with a one way bearing is attached to the low speed gearbox hub. As the bullwheel turns in the correct direction, the one way bearing allows the mechanical arm to stay in one spot as the hub rotates.

If the bullwheel starts to reverse direction, the one way bearing causes the mechanical arm to rotate and trip the mechanical linkage that is connected to the hydraulic system. When tripped, it dumps the hydraulic pressure on the emergency brake causing it to close on the bullwheel.

During this incident, the rollback did not cause the hydraulic pressure to be dumped automatically, so the emergency brakes did not apply immediately when the lift reversed direction. Within 3-5 seconds, the lift operator moved the lever which caused the hydraulic pressure to be released thereby applying the emergency brakes.

Once the emergency brakes applied, the lift started to slow and came to a stop.

When tested manually, the linkage and cable arrangement removed pressure from the hydraulic system. The mechanical linkage was covered with paint and had some looseness. The cable connecting the mechanical linkage and to the hydraulic system was not tight and had play in it.

The mechanical arm was removed to facilitate removing the coupling and low speed torsion shaft. The one way bearing in the mechanical arm was destroyed.

Findings

It is critical that recommended maintenance procedures/ inspection intervals on gear sets and associated drive systems are followed and incorporated into the maintenance program.

The thrust bearing for the sun gear appears to have failed some time before the March incident but went unnoticed. This allowed the low speed torsion shaft and coupling to settle on top of the bullwheel hollow shaft which caused wear over time. The failure of the coupling teeth disconnected the bullwheel from the drive system. This caused the motor, service brake, high speed rollback pinion and high speed gearbox to become disengaged from the low speed gearbox.

The coupling that connects the high speed gear set to the low speed gear set failed, disconnecting the coupling from the low speed torsion shaft of the V-116 gearbox.

Maintenance procedures of ski areas need to be of sufficient detail to ensure the work is completed as intended by the engineer/manufacturer and material used is appropriate based on the ski area’s maintenance control program, the manufacturer’s procedures, jurisdictional requirements and the adopted standards.

As a result of this disengagement, two safety devices (the service brake and high speed rollback pinion) were unable to assist in stopping the lift or rollback. Once the lift was no longer being driven up the hill by the motor and momentum stopped, the haul rope moved in the reverse direction causing the bullwheel to reverse direction.

The drop dog/anti-roll back device failed to engage in the wedges on the bullwheel thereby allowing the lift to reverse direction for more than the 36 inches permitted in code.

This underspeed switch used to energize the solenoid that raises or lowers the drop dog will operate in either direction. Its actuation is only dependent on bullwheel rotational speed. Depending on the installation, the adjustment of the underspeed switch on the King Pine lift could be quite sensitive. If adjustment is needed, even minor adjustments can affect the operation of the drop dog making it function improperly.

Upon a reverse in direction, the automatic activation of the emergency brakes did not occur. The one way bearing/mechanical arm arrangement installed to actuate the mechanical linkage which removes hydraulic pressure to activate the emergency brake (bullwheel brake) in the event a bullwheel reverses rotation did not work as intended. A lift operator moved the lever up which opened the valve that dropped hydraulic pressure off the emergency brakes allowing them to apply. It is estimated that this action took 3 to 5 seconds. This delayed activation allowed the lift to increase in speed in the reverse direction.

Ski lift owners/operators need to work with manufacturers to determine what system updates/upgrades may be available for their lifts that would increase lift safety and reliability. Older lift systems may not be as reliable as new systems designed to fulfill the same function. For instance, even though not required by code, new and improved rollback detection systems are available. This lift did not employ the best available methods for detecting abnormal lift conditions.

The accident scene was not maintained as it should have been. While there is a need to make the scene safe, some of the lift's mechanical components were adjusted and/or removed prior to the investigation making it impossible to completely recreate or simulate the conditions that existed when the accident occurred.

Note: Pictures are in Appendix 1