Incident Summary #II-891565-2019 (#14795) (FINAL)

SUPPORTING INFORMATION	Incident Date		August 12, 2019
	Location		Vancouver
	Regulated industry sector		Amusement Devices - Amusement ride
	Impact – Injury	Qty injuries	0
		Injury description	N/A
		Injury rating	None
	Impact – Damage	Damage description	Failure of the upper gearbox on a pendulum type amusement ride
		Damage rating	Moderate
	Incident rating		Moderate
	Incident overview		While in operation for the public, a pendulum type amusement device was stopped by staff during a ride cycle because a strange noise was heard and oil was leaking from the top of the device onto guests seated on the ride, (Photo 1). The device was safely unloaded of passengers after coming to a complete stop, the device did not return to normal operation.
INVESTIGATION CONCLUSIONS	Site, system and components		A twenty passenger open gondola is attached to a pendulum arm. The gondola is loaded at the 6 o'clock position, and as the ride cycle is initiated, begins to swing with ever increasing speed and height until raised to 120 degrees from the starting point. This swinging action is facilitated through use of 2 sets of motor driven gearboxes located at the top of the device. The ride cycle is completed as swing height and speed decrease, until the gondola is returned to the 6 o'clock position, where passengers disembark.
	Failure scenario(s)		The south gearbox was identified as the damaged component, (Photo 2). Upon examination of the failed gearbox components, evidence of reverse bending fatigue was discovered on the components caused by high bending stresses applied on the gearbox during normal ride operation. According to further investigation, these bending stresses exceeded the fatigue endurance limits of steel components within the gearbox. Contributing factors include the bolted connections that hold the gearbox in place having become loose, or being installed without specific torque, or insufficient number of bolts connecting the gearbox motor to the cylinder casing.
	Facts and evidence		The gearbox was in service for 3 years, failure occurred after approximately 1500 hours, or 300,000 cycles (a cycle being one swing of the pendulum). The gearbox is attached to an electric motor drive also installed at the top of the A-frame structure. The motor is attached to the gearbox and is aligned to the gearbox using two adjustable threaded rods, one is shown in Photo 3.

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	The mechanical failure had been detected when the operator heard loud “bangs” from the vicinity of the gearbox and observed oil spilling from the top of the device’s South gearbox. There were reports of a knocking or “clunking” sound in the months leading up to the south gearbox failure. Maintenance logs (records) listed on May 21, 2019, noted a hard stop to the ride and a loud noise, a possible indication that cracking had initiated. Initial inspection after the incident found the snap ring was pushed out of position by gearbox end plate, likely due to axial load, (Photo 4). An independent engineering firm was retained to remove and dismantle the gearbox for detailed inspection and failure analysis. Initial visual investigation before disassembly also found that the end plate of the inboard end of the gearbox was partially separated (opened), (Photo 5). This separation was determined to be due to excessive axial loading. The excessive loading had also caused bolts to be broken due to overload. The gearbox was removed for thorough examination at a metallurgical laboratory to verify the cause of failure. During full disassembly, upon removal of the end plate and third stage fasteners, significant damage was discovered. All four of the posts were fractured on the planetary gear carriage, fracture of many sun gear teeth, and complete fracture of one planet gear, (Photos 6 & 7). No other indications of damage were found on any other components of the device. Metallurgical failure analysis was conducted. No material deficiencies were found. Failure was determined to be due to formation and propagation of fatigue cracking initiated by excessive reverse bending stresses on the planetary gearbox, (Photos 8 & 9). The bending stresses exceeded the fatigue endurance limit of the metal components. It is possible that the reverse bending stresses were due to the mounting fastener bolts not being sufficiently tight, and/or an insufficient number of motor alignment rods. It was possible that the bending stresses that lead to failure were due to bolted connections that hold the gearbox in place having become loose during ride operation or being installed without sufficient torque for the mounting bolts to remain securely fastened. The North gearbox had a similar failure earlier in the year prior to the South gearbox failure. The damage mechanism was reported to be identical for the North gearbox. In both failures, damage was isolated to the gear box and involved destruction of the internal components.
Causes and contributing factors	It is likely that the design and robustness of the gearbox, was inadequate to maintain loads necessary for the normal operation of the device, over its expected lifespan. A possible contributing factor was inadequate fastening of the gearbox motor mounting bolts.

Photographs attached:

Photo 1: A-framed pendulum type amusement device, [Lab report].

Photo 2: South side gearbox location.

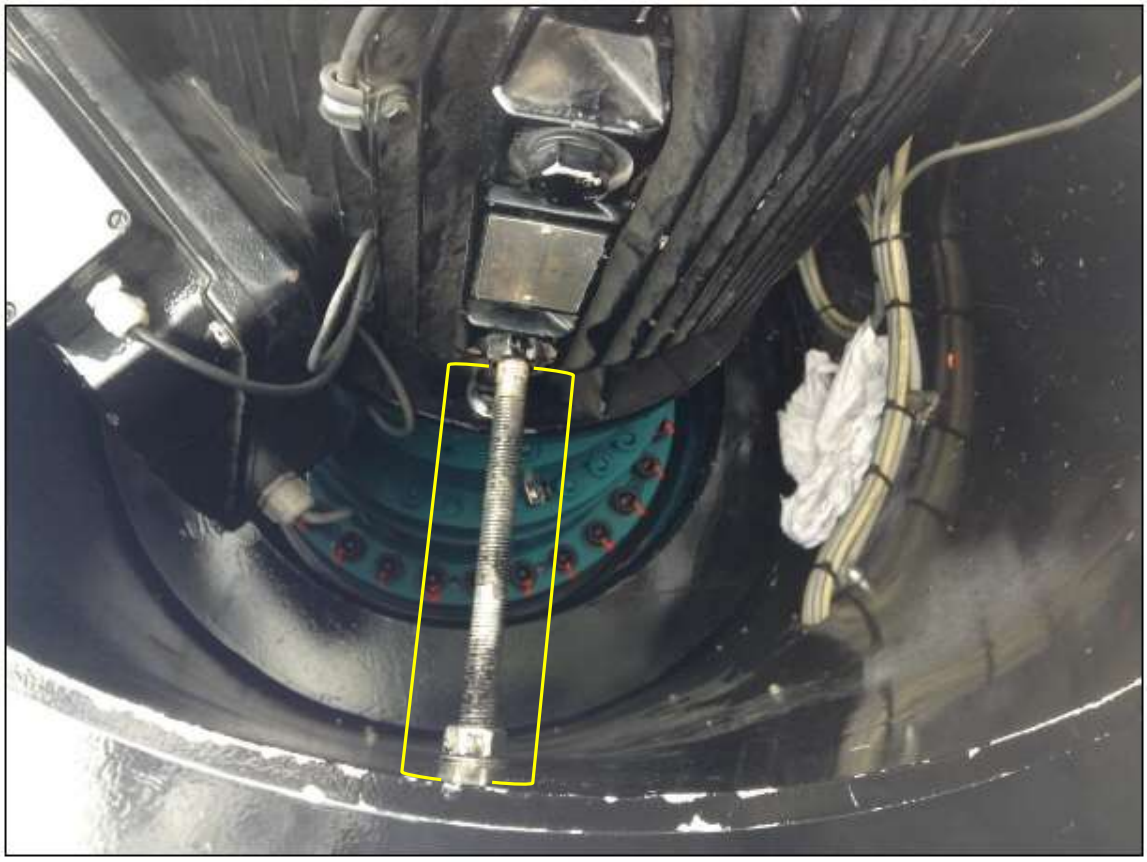

Photo 3: Threaded fastener aligning drive motor to cylinder and gearbox, outlined in yellow, [Lab report].

Photo 4: Initial inspection, snap ring pushed out of position by gearbox end plate, due to axial load.

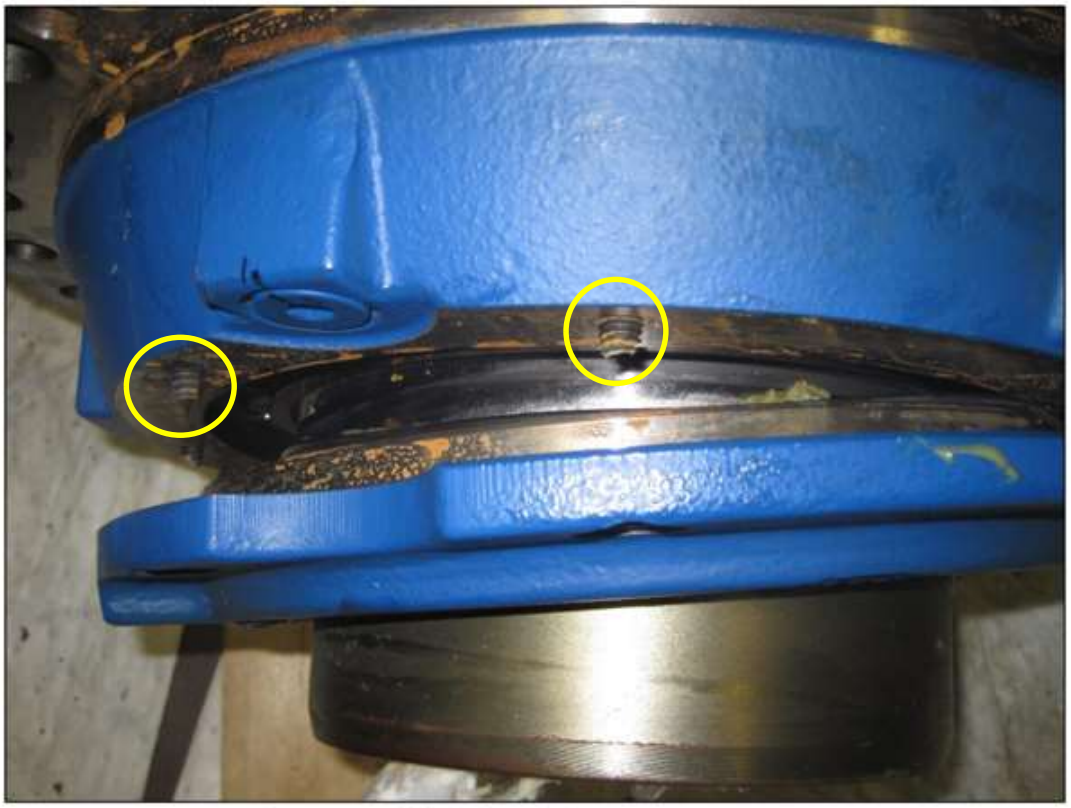

Photo 5: End plate separated from gearbox housing and bolts fractured (circled), [Lab report].

Photo 6: Gearbox Stage 3 Planetary gear set damage, complete fracture of all four posts, [Lab report].

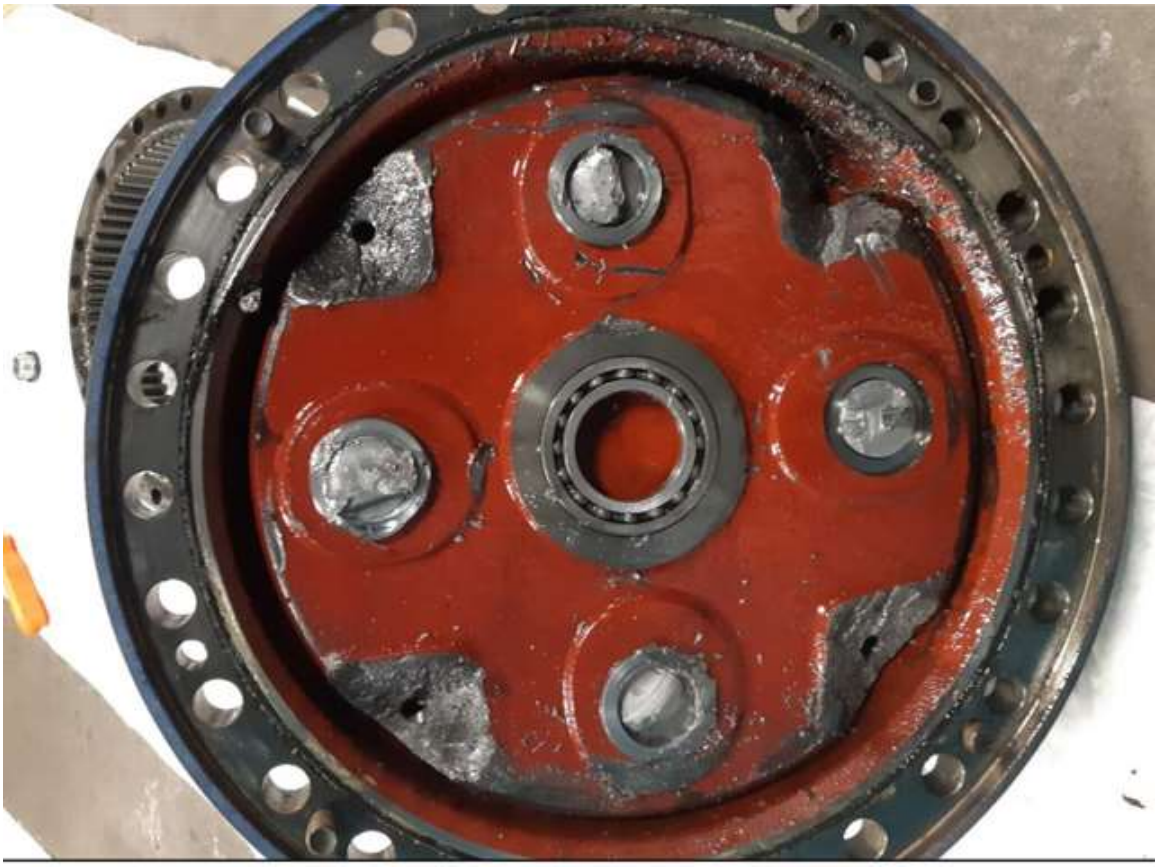

Photo 7: Gearbox Stage 3, planetary gear carriage, fractured gear posts and carrier plate, [Lab report].

Photo 8: Planetary gear post fracture surface shows reverse bending fatigue cracking, [Lab report].

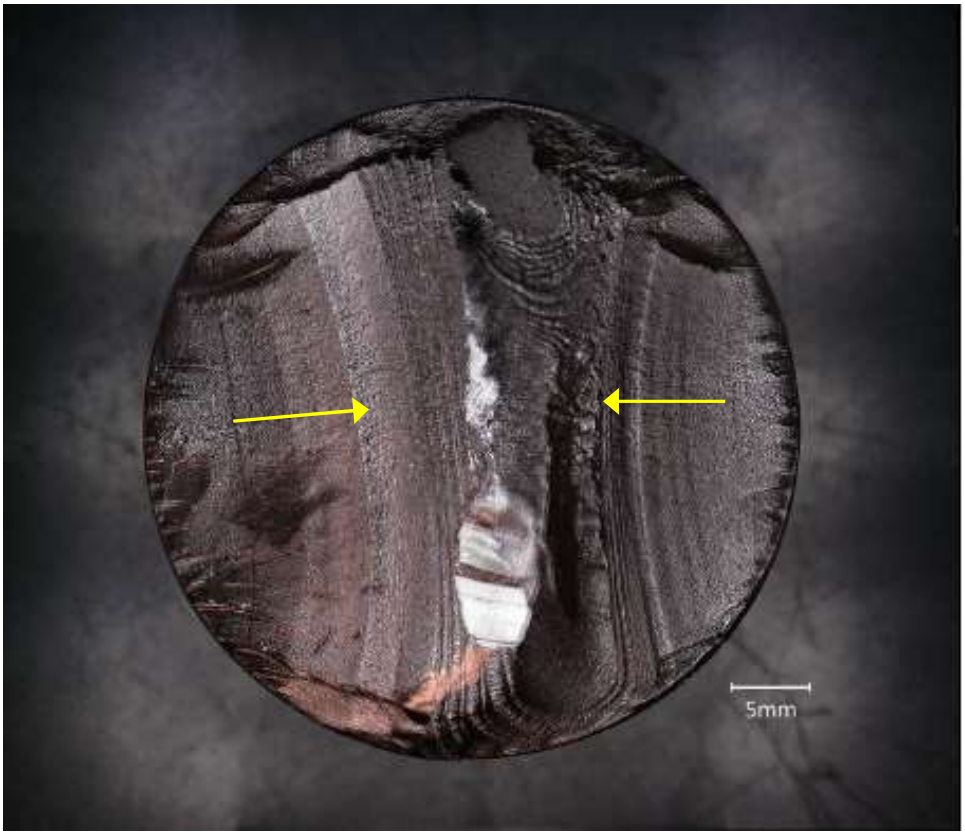

Photo 9: Close up of fracture surface showing fatigue cracking striations propagating in opposing directions. Arrows indicate crack propagation direction, [Lab report].