Span Drive Machinery Vibration at Hood Canal Bridge

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OVERVIEW

• Introduction and History
• Investigation/Evaluation
• Vibration Analysis
• Repair Design
• Vibration Issue Summary and Status
INTRODUCTION

- Location:
  - Hood Canal Bridge links the Olympic and Kitsap peninsulas in the Northwest corner of Washington State
Span Drive Machinery Vibration At Hood Canal Bridge
INTRODUCTION

• History:
  • Original bridge opened to traffic in 1961
  • February 13, 1979 the west half of the bridge sank during a severe wind storm
  • 1982 construction was complete on the west half replacement
  • 2009 the original east half was replaced and the west half was rehabilitated
• February 13th 1979: looking west
• West half of the bridge missing
• West half was replaced in 1982
  • Built stronger with three 100 foot lift decks to retract the draw span under. This allowed a straight alignment for traffic on the west half.
Bridge Operation Overview

- Two retractable draw spans that provide a 600 foot channel for marine traffic
- Each draw span is operated by 4 motors through a rack and pinion arrangement
- Each draw span retracts under three 100 foot-long roadway sections that are hydraulically lifted approximately 9 feet
Machinery Description

PONTOON ZD

COLUMN (TYP)

N

PONTOON NA

PONTOON NB
• 1980’s without a common machinery frame

• 2009 with a common machinery frame
• 1980’s replacement of the west half utilized grid couplings for the low speed couplings
• 2009 update to gear type couplings to meet current AASHTO
Start-Up of Rehabilitated System

- Commissioning of the rehabilitated systems:
  - Audible harmonic banging at certain RPM’s of the draw spans
  - Banging at both machinery assemblies
- West half operated satisfactory for almost 30 years prior to rehabilitation
- Components that were changed during replacement/rehabilitation were the main focus:
  - Drives
  - Machinery configuration
  - Low-speed couplings
Investigation/Evaluation

• The system behaved as if drives not load sharing
• Extensive efforts spent on tuning the drives
• Drive tuning eliminated as cause after drives tripped due to a limit switch fault. With no dynamic braking from the drives, relying only on the motor brakes, the oscillations were still present
  • The oscillations started around 500 RPM of the motor shaft and damped out below 200 RPM
• Lower gear box vibration assessment was recommended to identify the source of the audible oscillations
Vibration Analysis

• Analysis of field measurements
  • Pinion strain
  • Motor speed
Vibration Analysis

• Field measurements
  • Pinion strain
  • Motor speed
Vibration Analysis – Pinion Strain and Motor Speed

Hood Canal Bridge

- Pinion Shaft Strain
- ± 150% Full Load Torque
- Motor Speed

Time (seconds)

Motor Speed (RPM)

Tensile Microstrain at Pinion Shaft

DATA IS CLIPPED
Vibration Analysis – Pinion Strain and Motor Speed

Hood Canal Bridge

- Tensile Microstrain at Pinion Shaft
- Motor Speed
- Motor Speed (RPM)
- Time (seconds)

- Pinion Shaft Strain
- ± 150% Full Load Torque

Clipped

Not Clipped
Vibration Analysis

- Torsional analysis of drive machinery
  - Mass elastic model to determine the Torsional Natural Frequency (TNF)
- Rotational inertia
- Torsional stiffness
- Gear tooth counts
Vibration Analysis

- Torsional Analysis of Drive Machinery
- Mass elastic model to determine the Torsional Natural Frequency (TNF)
Vibration Analysis

- Vibration Analysis Conclusions
  - Resonance at approximately 5.5 Hz / ~ 500 rpm at motor
  - Coincides with gear mesh frequency between pinion / idler
Vibration Analysis

- Torsional analysis of drive machinery
  - Review of possible modifications
  - Target TNF well away from motor operating speeds

- Flywheels
  *Lowers TNF, but still in operating range*

- Geislinger Coupling
  *Insufficient room for installation*
Vibration Analysis

• Review of possible modifications
  • Modified Upper Gearbox – changes to length of shaft and shaft diameter
    *Added cost, limited benefit*
  • Modified lower gearbox – changes to length of shaft and shaft diameter
    *Limited impact on its own*
Vibration Analysis

• Review of possible modifications

• Change to output coupling

*Grid coupling is “torsionally soft” compared with existing gear coupling – Impact?*
Vibration Analysis

- Changed output coupling - damped response

Torsional Load Response Plot

Vibratory Torque due to Resonance with Gear Mesh
Low Speed Shaft, Stn (27):

- Existing Vibratory Response
- Recommended LS Grid Coupling
Vibration Analysis

• Summary of reviewed modifications

Reviewed

• Rigidity of lower gearbox
• Coupling changes
• Flywheels
• Stiffening lower gearbox pinion shaft
• Stiffening upper gearbox pinion shaft
• Changing brake wheel

Concluded

• Lowering TNF possible but still within motor operating speed range
• Difficult to raise TNF substantially – many changes required to put slightly outside of operating range – risk if does not work
• Coupling changes largest impact
Other Issues

- Poor coupling hub fits
- Poor gear coupling alignment
Other Issues

- Bearing damage
Other Issues

- Bearing damage
- Speed reducer gear pitting
Repair Design

- Design details
- Maintain existing adjustability with pin and slotted holes

Frame Rotates About Bed Plate Pin To Change Engagement At Idler and Rack

Rack
Idler
Pinion
Bed Plate Pin
Repair Design

- Design details
- Change low speed coupling from gear to grid coupling
Repair Design

- Design details
- Improved maintenance - Ease of disassembly / inspection
Repair Design

• Design details
  - Increase in rigidity of lower box assembly
Repair Design

• Design details
• Improved maintenance - change in bearing lubrication provisions
VIBRATION ISSUE SUMMARY AND STATUS

• Vibration issue following 2009 repairs
• Initial evaluation concluded resonance issue
• Vibration analysis confirmed issue and used to vet new design
• Not practical to modify the machinery TNF to avoid operating speeds
• Design included change from gear to grid coupling for damping
• Address other existing issues and improve where possible
• Status - good results with no reported issues