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MECHANICAL AND ELECTRICAL SYSTEMS
BURLINGTON NORTHERN RAILROAD BRIDGE AT PORTLAND

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INTRODUCTION

The purpose of this paper is to present some of the features used in the mechanical and electrical drive and control system for the Burlington Northern Railroad's vertical lift bridge over the Willamette River in Portland, Oregon. The lift span is of the span drive type using machinery reducers connected to operating drums at each corner of the span. D. C. Shunt Wound electric motors located at the center of the lift span provide the power necessary to raise and lower the lift span.

HISTORY

The Burlington Northern Railroad crossing of the Willamette River in Portland, Oregon consisted of multiple double track railroad truss spans. Included in the crossing was a 521 foot long double track swing span. The United States Coast Guard declared the swing span as a hazard to navigation and issued and Order to Alter under provisions of the Truman Hobbs Act as amended. Because of the Order to Alter, the Burlington Northern Railroad engaged the firm of Howard, Needles, Tammen & Bergendoff as engineering consultants to provide assistance in complying with the requirements of the Order to Alter.

STRUCTURAL CONCEPT STUDIES

In order to comply with the requirements of the United States Coast Guard, the width of the existing navigation channel had to be significantly increased. The increase in the channel width requirement effectively limited the type of movable span to a vertical lift.

An inspection of the existing bridge indicated that the structure was in a condition such that a totally new structure crossing was not to be considered.

Because of this condition an off-line replacement of the existing crossing was deleted as an option.

The site conditions, in combination with the type of marine traffic in the area, eliminated the option of a major shift in the sailing line in the river. The St Johns Bridge, a two lane highway bridge, downstream of the site required the retention of the existing sailing line at that location. The marine traffic in the area includes ocean going vessels. These vessel requirements with regard to safe turning radii without the use of tug assistance eliminated the option of any major shift in the existing sailing line between the St Johns bridge and the site.

The requirements previously discussed indicated that the new lift span should be placed in the location of the existing swing span. Once this decision was reached, the length of the lift span was determined based upon the physical restraints of the adjacent spans and the minimum navigation channel requirements through the site during reconstruction.

MECHANICAL AND ELECTRICAL CONCEPT STUDIES

GENERAL

The structural concept studies concluded that the lift span was to be a double track structure with a length of 516 feet center to center of bearings. Navigation requirements also required that the lift span be raised a distance of about 150 feet to meet the needs of navigation. These requirements were used as a basis for studying the various options for the drive and control system for the lift span. Options studied and presented to the Burlington Northern Railroad included the use of a tower drive, a span drive and a combination of the two.

TOWER DRIVE

A tower drive system places the drive system at the top of the towers at each end of the lift span. The span is normally raised and lowered by forcing the suspending rope sheaves on top of the towers to rotate. The sheave rotation is normally forced by mounting a gear on the sheave and driving this gear with a pinion gear. The pinion gear is rotated by a system of either gear reducers or a hydraulic system connected to electric drive motors. Friction between the suspending rope sheaves and the suspending ropes transfers the necessary moving force to the suspending ropes causing the lift span to either raise or lower.

In order to equalize the amount of movement of the lift span on each end, the electrical control system must monitor the movement at each end and make minor speed adjustments to one end or the other. This is required because the normal speed of each end will be effected by the amount of span imbalance, or load, and the operating characteristics of the drive system. The amount of load will not be exactly the same for each end and the drive characteristics at each end will not be identical.

For this bridge, a total of four suspending rope sheaves were required in order to support the lift span and counterweight at each tower. This unusual requirement reduced the available space for the normal tower drive machinery. Because of this restriction, the top of the tower would have to be larger than would be required for a span drive or a more normal tower drive bridge.

SPAN DRIVE

A span drive places the drive machinery on the lift span. Uphaul and downhaul operating ropes are located at each corner of the lift span. These ropes are attached to operating drums. Rotating the drums in one direction will cause the uphaul ropes to wind onto the drums and the downhaul ropes to unwind causing the lift span to raise. Rotating the drums in the other direction will cause the lift span to lower.

In order to equalize the amount of movement of the lift span on each end, the operating drums are mechanically connected to each other through a system of gear reducers and shafting to a common prime mover. This mechanical interconnection will cause each of the operating drums to rotate the same amount.

COMBINATION DRIVE

The combination drive studied consisted of placing uphaul ropes, downhaul ropes, and operating drums at each corner of the lift span. The operating drums at each end were then connected through a system of reducers and shafting to a prime mover located at each end of the lift span.

In order to equalize the amount of movement of the lift span at each end, the control system is required to equalize the speed of the prime movers in a similar manner as that used for a tower drive system.

ALTERNATIVE ADVANTAGES

Each of the systems studied have relative advantages with respect to each other. These were presented to the Burlington Northern Railroad for their consideration.

The tower drive system has the advantage of reducing the cost of the mechanical system versus a span drive. This cost reduction is mainly the cost of the drive shafting required to connect each end of the lift span.

The tower drive system has the advantage of reducing the size and the cost of the structural members of the lift span. This reduction is due to the fact that the lift span is not required to support the weight of the longitudinal shafting and the machinery required at the center of the span.

A span drive system has the advantage of a simpler and less expensive control system versus a tower drive. This simplification and cost reduction is due to the centralization of the equipment and monitoring and speed adjusting capabilities are not required.

A span drive system has the advantage of less frequent maintenance adjustments versus a tower drive. As previously described, the moving force is transmitted to the lift span via friction between the suspending rope sheaves and the suspending ropes for a tower drive system. The coefficient of friction required to prevent rope slippage is well below any reasonably expected actual friction coefficient. Because of this fact, slippage between the suspending ropes and their sheaves should not occur. In actual fact, slippage does occur. This slippage is minor in nature and does not create a major problem. It does require an adjustment of the control system periodically in order to zero out any monitoring errors caused by the rope slippage.

The combination drive system has the advantage of reducing the machinery and structural costs to a level similar to that of a tower drive. The combination drive also has the advantage of less frequent maintenance adjustments of the span drive. The main disadvantage is it's more complex tower drive type electrical power and control system.

SELECTED DRIVE SYSTEM

The Burlington Northern Railroad selected the span drive system for this bridge. The United States Coast Guard agreed to participate in the cost of the alteration based upon this decision. The author is not familiar with all of the reasoning used in reaching this decision but some of the considerations have been assumed.

The Burlington Northern Railroad personnel are more used to the span drive system. Most, if not all, of their lift spans are of the span drive type.

The additional cost of the structural system is minimal. Although the weight of the machinery located throughout the length of the lift span is not a negligible amount, the percentage increase with respect to the total weight is not large. Because the lift span is required to support a double track structure, the supporting members required to provide adequate support is very large when compared to the additional amount required to provide the support of the machinery. This ratio is much closer to unity than would be the equivalent ratio if the lift span had only to support a single railroad track.

FINAL MECHANICAL SYSTEMS

SUSPENDING ROPES AND TOWER SHEAVES

The dead load of the lift span was about 3940 tons. In order to support this weight, 144 - 2 1/2 inch wire ropes were used. These ropes were supported by 4 sheaves at each end with each sheave supporting 18 ropes. The ropes were specified to be improved plow steel 6X25 FC wire ropes with a factor of safety of 8 against breakage. This conforms to the AREA Recommendations.

Spherical roller bearings, designed to AREA requirements, were provided at the tower sheaves to minimize friction losses at this location. According to the Torrington Company, who provided the bearings, these were the largest spherical roller bearings installed on a vertical lift span. The expansion or floating bearings have a 800 mm (31.5 inch) bore and the fixed bearings have a 900 mm (35.4 inch) bore. The fixed bearings had to be larger because of the AREA requirement that they be capable of resisting a sideways thrust load of 15 percent of the radial load in addition to the radial load.

The tower sheaves are composed of ASTM A36 steel weldments in combination with a steel forging for the hubs. The steel weldments were stress relieved by heat prior to final machining. Additional non destructive testing was conducted after machining in order to provided additional quality assurance. The pitch diameter of the sheaves is 200 inches (16 feet 8 inches) or 80 times the diameter of the suspending ropes. The sheave shafts are composed of an ASTM A668 steel forging with a diameter of 42 inches at the sheave.

The sheaves were fabricated in Montgomery, Alabama and shipped by rail to the bridge site. Due to the size and weight of the combined sheaves and shafts, only one sheave assembly was shipped on a low boy flatcar. Again, due to the size, only one special car was used for transport between Montgomery and Portland.

AUXILIARY COUNTERWEIGHT

The large number and size of the suspending ropes in combination with the 150 foot lift height would have created an excessive amount of span imbalance loads unless a rope counterbalancing system was provided.

Two methods have been normally used for the counterbalancing of the suspending rope weight. One is balance chains and the other is an auxiliary counterweight. Balance chains were considered to be a source of maintenance problems especially in the damp environment of the bridge. In addition balance chains are being abandoned by the industry as evidenced by the AASHTO Specifications recent change from recommending balance chains to now recommending an auxiliary counterweight.

The auxiliary counterweight at each end of the lift span is anchored to the lift span. The auxiliary counterweight is connected to these anchorages by 6 - 1 1/4 inch wire ropes. The current specifications does not specifically address requirements for these wire ropes. The specifications for the main suspending ropes were followed in order to gain maximum life for these ropes. The wire ropes pass over deflector sheaves such that the auxiliary counterweight exerts a maximum upward pull on the span when the span is down and a maximum downward pull on the span when the span is up. At mid lift, the auxiliary counterweight has no effect on the lift span. This type of layout provides for the maximum efficiency of the auxiliary counterweight. Using this type of layout, the auxiliary counterweight need only weigh about one half the amount of the required balance adjustment.

Deflector sheaves are mounted at each main front tower leg near mid lift of the span and also at the top of the towers. This layout is such that the auxiliary counterweight is located within the tower columns and also provides for maintenance access for most of the system at the top of the towers. This minimizes the cost of additional maintenance platforms.

OPERATING ROPES

The lift span machinery was designed to accommodate a dead load imbalance of 54,000 pounds span heavy in the span down position. In addition other loads specified by the AREA codes were used with the exception of ice. In this location, where light misty rains are frequent during the winter months, a heavy ice buildup can be expected to occur. Because of this condition, the ice loading used was greater than the normal code values. The method of treatment of this heavier than normal load with regard to the machinery and electric drive motors will be discussed later.

In order to provide for the design hoisting loads as described, 2 uphaul and 2 downhaul ropes were used at each corner of the lift span. Each rope is 1 3/4 inch 6X25 FC improved plow steel wire ropes. A factor of safety of 6 against direct loads was provided for each of the ropes as included in the AREA Recommendations. Each of the four ropes at each corner are anchored to their operating rope drum. The uphaul ropes are also anchored at the top of the towers and the downhaul ropes are anchored at the bottom of the towers.

Each of the operating ropes were provided with their individual length adjustment devices. These devices are necessary to accommodate both initial and future stretching of the operating ropes. The contract requirements specified that the operating ropes be prestretched. The AREA codes do not make this requirement but due to the length of the ropes required, it is an advantage to eliminate as much of the initial rope stretch as practical in order to minimize the amount of necessary rope length adjustment. The take-ups provide for a one percent increase in the length of the ropes in the future as well as provisions for some initial rope stretch due to loss of prestretch. The take-ups are also designed to permit manual adjustment by one person without the use of excessive force.

OPERATING ROPE DRUMS

The operating rope drums and their supporting frames were fabricated from ASTM A36 steel weldments. The weldments were heat stress relieved after welding and prior to final machining. Additional non destructive testing of the weldments was performed after machining to provide additional assurance of a sound quality product.

The operating drums are rotated by providing spur gearing bolted to the drum and a pinion gear mounted on the drum frame. The gear was bolted to the drum to ease future replacement in the event that this becomes necessary.

The operating drums and driving pinions are mounted with the use of spherical roller bearings. Roller bearings were used to minimize friction in these highly loaded bearings. The spherical roller bearings were sized to provide a B-10 life of 40,000 hours as required by the AREA. Because of this requirement, it is not anticipated that these bearings will ever have to be replaced.

MACHINERY REDUCERS

Machinery reducers are provided to reduce the rotational speed of the operating drums and to increase the torque at the operating drums from that provided by the electric motors. The electric motors are connected to a parallel shaft reducer at mid-span. An additional reducer is provided at each end of the lift span. These reducers are spiral bevel reducers in order to change the direction of the shafting. Thus a total of three reducers are provided on the bridge.

All machinery reducers are totally enclosed and were designed to and were required to conform to AGMA Standards. The reducer requirements included minimum design service factors of 1.5 for strength and 1.0 for durability requirements based on 100 percent full load torque of the electric motors. The service factors for strength are greater than those for durability in order that a more balanced and more economical design can be provided for the application. Durability requirements can be reduced because the actual number of hours of operation of the reducers is not large in comparison to an industrial environment.

DRIVE SHAFTING

Drive shafting must be provided the full length of the lift span and to each side of the span at each end. The shafting is supported by spherical roller bearings for consistent maintenance requirements with those bearings provided due to their load and friction requirements.

The size of the shafting is larger than normal due to the loads being transmitted for this unusually large and heavy lift span. The line shafts, which run the length of the bridge, were required to be a minimum of 5 3/16 inches in diameter and the cross shafts, which run transverse to the bridge at each end, were required to be a minimum of 10 1/2 inches in diameter. The sizes were required in order to limit the torsional stresses to within the AREA Recommended values.

Floating shafts were specified to be installed at each end of each shafting run in order to simplify installation and alignment in the field.

Each end of each shafting section was coupled to each other or to machinery components using standard gear couplings of the flex-rigid type.

MACHINERY SUPPLIERS

Steward Machine Company, Birmingham, Alabama, was the Sub-contractor who provided the machinery for this project. Machinery reducers were manufactured by Horshburg & Scott and the roller bearings were provided by the Torrington Company.

FINAL ELECTRICAL SYSTEMS

MAIN ELECTRICAL DRIVE SYSTEM

The lift span prime movers consist of two D. C. Shunt Wound Drive Motors. Primary control is provided by Silicon Controlled Rectifiers (SCR) drives. Each motor is rated at 200 HP at a base speed of 500 RPM.

The size of the electric motors for this bridge was a significant design feature. Alternative designs were provided in the preliminary design phase before the motor size was finally selected. The horsepower requirements for a given site and loading condition is a function of the time required to raise or lower the span. The final selection was approved by the Burlington Northern Railroad and the United Stated Coast Guard after considerable discussion. The main discussion revolved around the time of operation versus the cost of the system. The final time of operation to raise or lower the lift span is 3 minutes and 10 seconds. This time was agreed to by both parties but is longer than that required to open the existing swing span. This time is for normal operation and is increased per AREA code ratios. Times of operation will be discussed more in the Controls section.

AUXILIARY DRIVE SYSTEM

In the event of a failure of the primary electrical drive system, an auxiliary or emergency drive system has been provided. The auxiliary drive system is a hydrostatic drive (hydraulic drive motor) connected to the main drive machinery at the central reducer. Primary power for the hydraulic motor is provided by a 200 HP AC Squirrel Cage 480 V-3 phase 1800 RPM motor. A soft-start starter is provided for this motor in order to limit the starting inrush current to this motor.

The hydraulic system provided is a hydrostatic drive which was designed and manufactured by the Falk Corporation. Variable speed control and positioning of the span is by an independent solid state control system from that used for the primary control.

The auxiliary drive is normally disengaged from the main drive system. When this system is required, it can be engaged to the main drive machinery within the machinery room at mid-span by the use of a cut-out coupling. An electrical limit switch is located at the cut-out coupling for an interlock check. The main electric drive motors cannot be engaged if the auxiliary drive system is connected to the main drive machinery.

The auxiliary drive consists of a variable speed hydraulic pump connected to a high speed low torque (HSLT) hydraulic motor. 2 inch piping and hoses are used as the connection in order to limit fluid flow velocities to within AREA recommendations of 15 feet per second. The HSLT motor is connected to a totally enclosed machinery reducer with a ratio of 9 to 1. The low speed shaft of this reducer is connected to the main drive via the cut-out coupling.

The output speed of the auxiliary drive varies from 11 to 190 RPM. This results in a slower span speed than that of the main drive system. This reduction in speed permits the use of a smaller and less expensive system. This reduction is both permitted by the AREA recommendations and results in a more economical system for the rare times that it may be required.

A few more statistics for this system include a main pump capacity of 160 gallons per minute and a 15 1/2 gallon per minute charge pump. The maximum anticipated hydraulic pressures do not exceed the AREA recommendation of 2000 psi. under the most severe anticipated loads required to operate the span. The braking requirements remain with the main drive system electric thruster brakes in order to minimize costs.

ELECTRICAL CONTROL SYSTEM

Electrical control and interlocking is under the direction of a programmable logic controller (Plc). The Plc provides for all necessary sequence interlocking except for the interface between the operation of the bridge and the Railroad's signal system. This permissive interface is by a machine tool relay within the railroad's signal cabinet.

Upon initiation of a bridge movement, the entire range of movement of the span is under the direction of the Plc. Ramped acceleration, full speed, ramped deceleration, slow speed and ramped slow to stop deceleration is under the control of the Plc at all times. Span position is constantly monitored by a position resolver. Selected critical check points for position are monitored by limit switches. The critical location limit switches are used to compare actual position with the position indicated by the position resolver. If a significant difference exists between the limit switch and the resolver, the bridge tender is warned of a calibration error in the equipment.

When the bridge tender must raise the bridge, a "raise" command is initiated. The Plc then takes over the remaining control functions. Varying speed signals are sent to the drive motor controller(s) by the Plc causing the span to accelerate. When the desired final motor speed is attained, the Plc continues to send speed signals to the motor controller(s) but these are a constant value causing the span to run at a constant speed. At near open, the Plc receives input as to the span's location, at that time the Plc's speed signals decrease causing the span to decelerate until the final slow speed motor RPM is attained. The span then continues at the slow speed rate until the span reaches full open at which time the span location is input into the Plc and the Plc directs the drive controllers to slow the motors to zero RPM. When the span is stopped, the Plc directs the brakes to set. Throughout this operation, the Plc receives data from the resolver with regard to span position and motor RPM from a tachometer, the Plc uses this data to compare the desired motor speed with the actual speed, in the event that a significant discrepancy occurs between desired and actual speed, the Plc alarms the operator and proceeds bring the span to an emergency stop. Similar functions occur when the span is lowered.

The bridge tender does not need to provide any additional function beyond initiating the raise or lower commands in order to raise or lower the lift span. If desired, the bridge tender may stop the span at any intermediate position by depressing a "push to stop" pushbutton. This will signal the Plc to direct the drive controllers to bring the speed of the motors to zero at the preset rate, and after the bridge is stopped to set the brakes. The span may be either be restarted in the same or in the opposite direction from that location at the discretion of the bridge tender.

If during span operation, the bridge tender decides that the span is not operating properly, an emergency stop pushbutton may be depressed. The drive motors are de-energized and the brakes are immediately set when this button is pushed. These functions are not under the control of the Plc.

SYSTEM REDUNDANCY

The drive systems provided have redundant methods for operating the span under all conditions. This permits increased reliability for span operations. Under normal operating conditions, both main drive motors are used to operate the span. In the event that one of the main drive motors or it's controller is out of service, the other main motor is capable of operating the span under all normal operating conditions. In the event that both main drive motors or both motor controllers are out of service, the auxiliary drive system can then operate the bridge.

Redundancy exists for other than span drive motor options. In the event that the primary Plc fails for any reason, a duplicate Plc will come on line to continue span control functions. In the event that both Plc's fail, the span can still be raised or lowered. A total Plc failure does limit the operating conditions to a slower than normal speed because the sequence interlocking and automatic span control speed functions normally controlled by the Plc reverts to the bridge tender. Because, the bridge tender will not used to normally providing speed control input, slow speeds are required to prevent serious damage if the bridge tender fails to properly control the span.

OPERATION FEATURES

The normal operating condition will be with both electrical main drive motors operated at a speed of 870 RPM. This will provide for a full lift in 3 minutes 10 seconds. As previously stated, the base speed of the main drive motors is 500 RPM. At speeds above base speed, the motors act as constant horsepower, variable torque motors. The lift span may be operated in this configuration except under the most adverse loading condition of the extremely heavy ice loads which may occur.

In the event that one of the main drive motors or it's drive controller is out of service for any reason, the span may be operated normally by the other drive motor. Under this condition, the motor speed is maintained at it's base speed of 500 RPM in order to gain maximum use of its capabilities to deliver torque for span operation. This will provide for a full lift in 4 minutes 45 seconds. The lift span may be operated in this configuration except under the most adverse loading condition of the extremely heavy ice loads which may occur.

When the case of extremely heavy icing conditions exist, the bridge tender activates the ice load condition method of operation. The activation is by rotating a control switch on the control console. Under this method of operation, both main drive motors are used at their base speed of 500 RPM. Maximum operating torques are therefore available for this adverse condition. This will provide for a full lift in 4 minutes 45 seconds. The lift span may be operated under this configuration under the most severe operating loads anticipated to occur at this site.

In the event that both main drive motors or their controllers are out of service, the auxiliary drive system, previously described, may be used. This will provide for a full lift in 10 minutes. The lift span may be operated under this configuration under the most severe operating loads anticipated to occur at this site.

INCOMING POWER

Normal commercial electrical power is obtained from the local electrical power company at 480 volts, 3 phase, 4 wire Wye, 60 hertz. Sufficient power is available from this source to operate the drive system under it's most severe loading condition in combination with the other electrical loads necessary such as lighting and comfort conditioning.

In the event that there is an interruption of commercial power, an engine-generator is on site to provide necessary electrical power. The engine-generator is located on shore within it's own building. This building also houses the automatic transfer switch used to switch from the commercial power source to the engine-generator. The automatic transfer switch is of the auto-start auto-run type permitting power transfer without any input from the bridge tender. A built in time delay prevents transfer due to a momentary loss of commercial power. The engine-generator is capable of providing sufficient electrical power for all necessary electrical service in combination with either one main drive motor or the auxiliary drive motor. This permits span operation under all operating conditions without providing an unnecessarily large emergency source of electrical power.

GENERAL STATISTICS

The drive and control system moves a total weight of lift span, counterweight and auxiliary counterweight of about 7860 tons. This is believed to be the greatest mass of a movable span to date.

The greatest operating load applied at the operating ropes is anticipated to be 165 tons.

The final height of lift is 146 feet 3 inches. This provides for slightly more than 200 feet of vertical clearance above low water. Provisions exist for an additional 3 feet of lift. This permits time for the bridge tender to react in the event that normal stopping of the span does not occur and also provides an additional limit switch to signal the span to stop in the event that the normal full up switch fails to signal the span to stop.