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SINGLE-FAILURE-PROOF CRANES FOR NUCLEAR POWER PLANTS

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1. INTRODUCTION

A general requirement for design and operation of light-water reactors is that fuel storage and handling systems be designed to ensure adequate safety under normal and accident conditions. Overhead cranes are used to lift and transfer heavy component parts such as spent fuel casks and reactor vessel heads. When a load being handled by a crane can be a direct or indirect cause of release of radioactivity, the load is called a critical load.

NRC has licensed reactors on the basis that the safe handling of critical loads can be accomplished by adding safety features to the handling equipment, by adding special features to the structures and areas over which the critical load is carried, or by a combination of the two. When reliance for the safe handling of critical loads is placed on the crane system itself, the system should be designed so that a single failure will not result in the loss of the capability of the system to safely retain the load. This report identifies features of the design, fabrication, installation, inspection, testing, and operation of single-failure-proof overhead crane handling systems that are used for handling critical loads. These features are limited to the hoisting system and to braking systems for trolley and bridge. Other load-bearing items such as girders should be conservatively designed but need not be considered single failure proof.

The general value of existing standards is recognized in this report, and reliance is placed on quality levels indicated in CMAA Specification #70[1] and in ANSI B30.2.0-1967[2] as supplemented by the recommendations in the following sections of this report.

The typical plant layout for pressurized water reactors (PWRs) is such that two different cranes may be required to handle critical loads. One of these cranes is located in the spent fuel storage and transfer area where the largest critical load would be a spent fuel shipping cask. The other crane is located inside the containment structure over the reactor vessel where it is used to lift the reactor vessel head during refueling periods; this crane is called a polar crane because of the circular track for the bridge structure.

In the plant layout for the majority of the boiling water reactors (BWRs) designed and built, a single crane handles critical loads near the reactor vessel and at the spent fuel storage area. However, for recent BWR plant designs (BWR Mark 6), two cranes could be needed to handle critical loads.

2. SPECIFICATION AND DESIGN CRITERIA

2.1 Construction and Operating Periods

When an overhead crane handling system will be used during the plant construction phase prior to its intended service in the operating plant, separate performance specifications may be needed to reflect the duty cycles and loading requirements for each service. At the end of the construction period, changes to the crane system may be required to reflect the specifications for the permanent operating plant condition. For example, if the specification for the size of the hoist drive motor differs sufficiently for the two applications, the motor and the affected control equipment would have to be replaced or changed for the operating plant phase. Features and functions needed for the cranes during the plant construction period are not considered in this report except where the use of the crane during construction may influence its design and operation for the permanent plant operation.

If the load lifts during construction are heavier than those for plant operation, the performance specifications should include design criteria for a permanent crane for construction as well as for operation. The allowable design stress limits for the crane intended for plant operation should be those indicated in Table 3.3.3.1.3-1 of CMAA Specification #70 and reflecting the appropriate duty cycle in CMAA Specification #70. The sum total of simultaneously applied loads (static and dynamic) should not result in

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1 Copies may be obtained from the Crane Manufacturers Association of America, 1326 Freeport Road, Pittsburgh, Pennsylvania 15238.

2 Copies may be obtained from the American National Standards Institute, 1430 Broadway, New York, New York 10018.

stress levels causing permanent deformation, other than localized strain concentration, in any part of the handling system during either the construction or the operating phase. The effects of cyclic loading induced by jogging or plugging[3] an uncompensated hoist control system should be included in the design specification.

2.2 Maximum Critical Load

A single-failure-proof crane should be designed to handle the maximum critical load (MCL) that will be imposed. However, a slightly higher design load should be selected for component parts that are subject to degradation due to wear and exposure. This will provide a margin in the crane's load-handling ability before it drops below its MCL capacity. An increase of approximately 15% of the design load for these component parts would be a reasonable margin. The MCL rating should be clearly marked on the crane.

Certain single-failure-proof cranes may be required to handle occasional noncritical loads of magnitude greater than the MCL during plant maintenance periods. For such cases, the maximum noncritical load will be the design rated load (DRL). The design of certain components may be decided to a greater extent by the MCL rating even though standard commercial practice may be used for the DRL rating. The DRL rating should be marked on the crane separately from the MCL marking.

2.3 Operating Environment

The operating environment, including maximum and minimum pressure, maximum rate of pressure increase, temperature, humidity, and emergency corrosive or hazardous conditions, should be specified for the crane and lifting fixtures.

For cranes inside the containment structure, the closed box sections of the crane structure should be vented to avoid collapse during containment pressurization. Drainage should be provided to avoid standing water in the crane structure.

2.4 Material Properties

Cranes are generally fabricated from structural shapes and plate rolled from carbon steel (no alloying elements except for 1% manganese in heavier section) or low-alloy steel (less than 5% total alloy content). Some of these steel parts exceed 12 mm (1/2 in) in thickness and may have brittle-fracture tendencies when exposed to lower operating temperatures so that testing of the material toughness becomes necessary. When low-alloy steels are used, weld metal toughness is of greater concern than the base metal.

However, it may be impractical to perform toughness tests for cranes that have progressed too far in the manufacturing sequence or for cranes already built and operating. Such cranes should therefore be tested by subjecting the crane to a test lift at the lowest anticipated operating temperature. It is desirable to include the crane manufacturer in the planning of the test.

Minimum operating temperatures should be specified in order to reduce the possibility of brittle fracture of the ferritic load-carrying members of the crane. In order to ensure resistance to brittle fracture, materials for structural members essential to structural integrity should be tested in accordance with the following impact test requirements. Either drop weight test per ASTM E-208[4] or Charpy tests per ASTM A-370[4] may be used for impact testing. The minimum operating temperature based on the drop weight test should be obtained by following procedures in paragraph NC-2300 of Section III of the ASME Code.[5] The minimum operating temperature based on the Charpy V-notch impact test should be obtained by following the procedures in paragraph ND-2300 of Section III of the ASME Code. Alternative methods of fracture analysis that achieve an equivalent margin of safety against fracture may be used if they include toughness measurements on each heat of steel used in structural members

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3 Jogging is defined as the momentary application of power to the drive motor for the purpose of promoting a limited movement. Plugging is a method of manual control by which the power to the motor is reversed to achieve deceleration or braking.

4 Copies may be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

5 Copies may be obtained from the American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, New York 10017.

essential to structural integrity. In addition, the fracture analysis that provides the basis for setting minimum operating temperatures should include consideration of stress levels; quality control; the mechanical checking, testing, and preventive maintenance program; and the temperatures at which the DRL test is run relative to operating temperature.

These toughness recommendations were developed at a time-when typical material section thickness for crane girders was a maximum of 51 mm (2 in). However, later information indicates that material thicknesses of 102 mm (4 in) or more may be needed for some applications. The rules for ASME Code Class 3 charpy testing do not make any adjustments for thicknesses greater than 64 mm (2 1/2 in), and for this reason it is felt that the NC-2300 and NO-2300 requirements give equivalent requirements only for the smaller thicknesses. For thicknesses over 64 mm (2 1/2 in), it is recommended that the NC-2300 requirements be used exclusively.

As an alternative to the above recommendations, the crane and lifting fixtures for cranes already fabricated or operating may be subjected to a coldproof test consisting of a single dummy load test as follows: Metal temperature of the structural members essential to the structural integrity of the crane handling system should be at or below the minimum operating temperature. The corresponding dummy load should be equal to 1.25 times the MCL. If the desired minimum operating temperature cannot be achieved during the test, the minimum operating temperature should be that of the test until the crane is retested at a lower temperature. The coldproof test should be followed by a nondestructive examination of welds whose failure could result in the drop of a critical load. The nondestructive examination of critical areas should be repeated at 4-year intervals or less.

Cranes and lifting fixtures made of low-alloy steel such as ASTM A514 should be subjected to the coldproof test in any case.

Cast iron should not be used for load-bearing components such as rope drums. Cast iron may be used for items such as electric motor frames and brake drums.

2.5 Seismic Design

Overhead cranes may be operating at the time that an earthquake occurs. Therefore, the cranes should be designed to retain control of and hold the load, and the bridge and trolley should be designed to remain in place on their respective runways with their wheels prevented from leaving the tracks during a seismic event. If a seismic event comparable to a safe shutdown earthquake (SSE) occurs, the bridge should remain on the runway with brakes applied, and the trolley should remain on the crane girders with brakes applied.

The crane should be designed and constructed in accordance with regulatory position 2 of Regulatory Guide 1.29, "Seismic Design Classification." The MCL plus operational and seismically induced pendulum and swinging load effects on the crane should be considered in the design of the trolley, and they should be added to the trolley weight for the design of the bridge.

2.6 Lamellar Tearing

Bridge and trolley structures are generally fabricated by welding structural shapes together. Problems have been experienced with weld joints between rolled structural members. Specifically, subsurface lamellar tearing has occurred at the weld joints during fabrication, and the through-thickness strength of the material has thus been reduced. When weld joints are carefully designed and fabricated, lamellar tearing is not expected to occur, but for certain weld joints it may be necessary to examine the joint by radiography or ultrasonic inspection, as appropriate, to ensure the absence of lamellar tearing in the base metal and the soundness of the weld metal.

All weld joints whose failure could result in the drop of a critical load should be nondestructively examined. If any of these weld joint geometries would be susceptible to lamellar tearing, the base metal at the joints should be nondestructively examined.

2.7 Structural Fatigue

Since each crane loading cycle will produce cyclic stress, it may be necessary to investigate the potential for failure of the metal due to fatigue. If a crane will be used during the construction period, it will experience additional cyclic loading, and these loads should be added to the expected cyclic loading for the permanent plant operation when performing the fatigue evaluation.

A fatigue analysis should be considered for the critical load-bearing structures and components of the crane handling system. The cumulative fatigue usage factors should reflect effects of the cyclic loading from both the construction and operating periods.

2.8 Welding Procedures

Problems with welding of low-alloy steels can occur if the base metal temperature is not properly controlled during welding and the postweld heat treatment.

Preheat temperatures and postweld heat-treatment (stress relief) temperatures for all weldments should be specified in the weld procedure. Welds described in the recommendations of Section 2.6 should be postweld heat treated in accordance with Subarticle 3.9 of AWS D1.1, "Structural Welding Code."[6]

3. SAFETY FEATURES

3.1 General

Numerous applications have been reviewed by the NRC staff, and the need for inclusion of certain safety features and the magnitudes of specific operational limits to provide, adequate safety have been determined.

A crane handling system includes all the structural, mechanical, and electrical components that are needed to lift and transfer a load from one location to another. Primary or principal load-bearing components, equipment, and subsystems such as the driving equipment, drum, rope reeving system, hooks, blocks, control systems, and braking systems should receive special attention.

3.2 Auxiliary Systems

All auxiliary hoisting systems of the main crane handling system that are employed to lift or assist in handling critical loads should be single failure proof.

Auxiliary systems or dual components should be provided for the main hoisting mechanism so that, in case of subsystem or component failure, the load will be retained and held in a stable or immobile safe position.

3.3 Electric Control Systems

It is important to prevent the release of radioactivity in case of failure, malfunction, or loss of load. It may be necessary to include special features and provisions to preclude system incidents that would result in release of radioactivity.

The automatic controls and limiting devices should be designed so that, when disorders due to inadvertent operator action, component malfunction, or disarrangement of subsystem control functions occur singly or in combination during the load handling, and assuming no components have failed in any subsystems, these disorders will not prevent the handling system from stopping and holding the load. An emergency stop button should be added at the control station to stop all motion.

3.4 Emergency Repairs

A crane that has been immobilized because of malfunction or failure of controls or components while holding a critical load should be able to hold the load or set the load down while repairs or adjustments are made. This can be accomplished by inclusion of features that will permit manual operation of the hoisting system and the bridge and trolley transfer mechanisms by means of appropriate emergency devices.

Means should be provided for using the devices required in repairing, adjusting, or replacing the failed component(s) or subsystem(s) when failure of an active component or subsystem has occurred and the load is supported and retained in the safe (temporary) position with the handling system immobile. As an alternative to repairing the crane in place, means may be provided for safely transferring the immobilized hoisting system with its load to a safe laydown area that has been designed to accept the load while the repairs are being made.

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[6] Copies may be obtained from the American Welding Society, 2501 N.W. 7th Street, Miami, Florida 33125.

The design of the crane and its operating area should include provisions that will not impair the safe operation or safe shutdown of the reactor or cause unacceptable release of radioactivity when corrective repairs, replacements, and adjustments are being made to place the crane handling system back into service after component failure(s).

4. HOISTING MACHINERY

4.1 Reeving System

Component parts of the vertical hoisting mechanism are important. Specifically, the rope reeving system deserves special consideration during design of the system. The load-carrying rope will suffer accelerated wear if it rubs excessively on the sides of the grooves in the drum and sheaves because of improper alignment or large fleet angles between the grooves. The load-carrying rope will furthermore suffer excessive loading if it is partly held by friction on the groove wall and then suddenly released to enter the bottom of the groove. The rope can be protected by the selection of conservative fleet angles. Ropes may also suffer damage due to excessive strain developed if the rope construction and the pitch diameter of the sheaves are not properly selected. Fatigue stress in ropes can be minimized when the pitch diameter of the sheaves is selected large enough to produce only nominal stress levels. The pitch diameter of the sheaves should be larger for ropes moving at the highest velocity near the drum and can be smaller for sheaves used as equalizers where the rope is stationary. Protection against excessive wire rope wear and fatigue damage can be ensured through scheduled inspection and maintenance.

Design of the rope reeving system(s) should be dual with each system providing separately the load balance on the head and load blocks through configuration of ropes and rope equalizer(s). Selection of the hoisting rope or running rope should include consideration of the size, construction, lay, and means or type of lubrication, if required, to maintain efficient working of the individual wire strands when each section of rope passes over the individual sheaves during the hoisting operation. The effects of impact loadings, acceleration, and emergency stops should be included in selection of rope reeving systems. The maximum load (including static and inertia forces) on each individual wire rope in the dual reeving system with the MCL attached should not exceed 10% of the manufacturer's published breaking strength.

The ratio of wire rope yield strength to ultimate strength may vary sufficiently for different production runs to influence the wire rope rating in such a manner that the initial safety margin selected would be too small to prevent the critical load from straining the wire rope material beyond the yield point under abnormal conditions. It would, therefore, be prudent to consider the wire rope yield strength as well as the ultimate strength when specifying wire rope in order to ensure the desired margin on rope strength.

The maximum fleet angle from drum to lead sheave in the load block or between individual sheaves should not exceed 0.061 rad (3-1/2°) at any one point during hoisting except that for the last 1 m (3 ft) of maximum lift elevation the fleet angle may increase slightly. The use of reverse bends[7] for running wire ropes should be limited, and the use of larger sheaves should be considered for those applications where a disproportionate reduction in wire rope fatigue life would be expected from the use of standard sheave diameters for reverse bends.

The equalizer for stretch and load on the rope reeving system may be of either beam or sheave type or combinations thereof. A dual rope reeving system with individual attaching points and means for balancing or distributing the load between the two operating rope reeving systems will permit either rope system to hold the critical load and transfer the critical load without excessive shock in case of failure of the other rope system.

The pitch diameter of running sheaves and drums should be selected in accordance with the recommendations of CMAA Specification #70. The dual reeving system may be a single rope from each end of a drum terminating at one of the blocks or equalizer with provisions for equalizing beam-type load and rope stretch, with each rope designed for the total load. Alternatively, a 2-rope system may be used from each drum or separate drums using a sheave equalizer or beam equalizer or any other combination that provides two separate and complete reeving systems.

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[7] A "reverse bend" is a configuration of two sheaves each providing 1.57 rad (90°) wire rope bends with the two adjacent planes of bending intersecting at an angle greater than 2.09 rad (120°). Two successive bends in the same direction and in the same plane and not reversed have an angle of 0 rad (0°). Two bends in opposite directions in the same plane (reverse bend) have an angle of 3.14 rad (180°).

4.2 Drum Support

Proper support of the rope drums is necessary to ensure that they would be prevented from falling or disengaging from their braking and control system.

The load hoisting drum on the trolley should be provided with structural and mechanical safety devices to limit the drop of the drum and thereby prevent it from disengaging from its holding brake system if the drum shaft or bearings were to fail or fracture.

4.3 Head and Load Blocks

The head and load blocks should be designed to maintain a vertical load balance about the center of lift from load block through head block and have a reeving system of dual design.

The load-block assembly should be provided with two load-attaching points (hooks or other means) so designed that each attaching point will be able to support a load of three times the load (static and dynamic) being handled without permanent deformation of any part of the load-block assembly-other than localized strain concentration in areas for which additional material has been provided for wear.

The individual component parts of the vertical hoisting system components, which include the head block, rope reeving system, load block, and dual load-attaching device, should each be designed to support a static load of 200% of the MCL. A 200% static-type load test should be performed for each load-attaching hook. Measurements of the geometric configuration of the hooks should be made before and after the test and should be followed by a nondestructive examination that should consist of volumetric and surface examinations to verify the soundness of fabrication and ensure the integrity of the hooks. The load blocks should be nondestructively examined by surface and volumetric techniques. The results of examinations should be documented and recorded.

4.4 Hoisting Speed

Maximum hoisting speed for the critical load should be limited to that given in the "slow" column of Figure 70-6 of CMAA Specification #70.

Selection of hoisting speed is influenced by such items as reaction time for corrective action for the hoisting movement and the potential behavior of a failed rope. To prevent or limit damaging effects that may result from dangerous rope spinoff in case of a rope break, the hoisting speed should be limited. The rope traveling speed at the drum is higher than at other points in the reeving system, and the potential for damage due to rope failing and interference with other parts of the system should be considered. Conservative industry practice limits the rope line speed to 1/4 m/s (50 fpm) at the drum.

4.5 Design Against Two-Blocking

A potential failure of a hoist travel-limit switch could result in a "two-block"[8] incident and in the cutting or crushing of the wire rope. In order to protect the wire rope, the reeving system should be designed to prevent the cutting or crushing of the wire rope if a two-blocking incident were to occur.

The mechanical and structural components of the complete hoisting system should have the required strength to resist failure if the hoisting system should "two-block" or if "load hangup"[9] should occur during hoisting. The designer should provide means within the reeving system located on the head or on the load-block combinations to absorb or control the kinetic energy of rotating machinery during the incident of two-blocking. As an alternative, the protective control system to prevent the hoisting system from two-blocking should include, as a minimum, two independent travel-limit devices of different designs and activated by separate mechanical means. These devices should de-energize the hoist drive motor and the main power supply. The protective control system for load hangup, a part of the overload protection system, should consist of load cell systems in the drive train or motor-current-sensing

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8 "Two-blocking" is the act of continued hoisting in which the load-block and head-block assemblies are brought into physical contact, thereby preventing further movement of the load block and creating shock loads to the rope reeving system.

9 "Load hangup" is the act in which the load block and/or load is stopped during hoisting by entanglement with fixed objects, thereby overloading the hoisting system.

devices or mechanical load-limiting devices. The location of mechanical holding brakes and their controls should provide positive, reliable, and capable means to stop and hold the hoisting drum(s) for the conditions described in the design specification and in this recommendation. This should include capability to withstand the maximum torque of the driving motor if a malfunction occurs and power to the driving motor cannot be shut off. The auxiliary hoist, if supplied, should be equipped with two independent travel-limit switches to prevent two-blocking.

4.6 Lifting Devices

Lifting devices that are attached to the load block such as lifting beams, yokes, ladle or trunnion-type hooks, slings, toggles, and clevises should be conservatively designed with a dual or auxiliary device or combinations thereof. Each device should be designed or selected to support a load of three times the load (static and dynamic) being handled without permanent deformation.

4.7 Wire Rope Protection

Sideloads would be generated to the reeving system if hoisting were done at angles departing from a normal vertical lift and resulting damage could be incurred in the form of excessive wear on sheaves and wire rope. A potential would also exist for the wire rope to be cut by jumping its groove barrier on the drum. If sideloads cannot be avoided, the reeving system should be equipped with a guard that would keep the wire rope properly located in the grooves on the drum.

4.8 Machinery Alignment

Power transmission gear trains are often supported by fabricated weldments of structural parts. The proper alignment of shafts and gears depends on the adequacy of bearings and their supports to maintain correct alignment of all components. The proper functioning of the hoisting machinery during load handling can best be ensured by providing adequate support strength of the individual component parts and the welds or bolting that binds them together. Where gear trains are interposed between the holding brakes and the hoisting drum, these gear trains should be single failure proof and should be of dual design.

4.9 Hoist Braking System

Mechanical holding brakes in the hoisting system (raising and lowering) that are automatically activated when electric power is off or mechanically tripped by overspeed devices or overload devices in the hoisting system will help ensure that a critical load will be safely held or controlled in case of failure in the individual load-bearing parts of the hoisting machinery.

Each holding brake should have more than full-load stopping capacity but should not have excessive capacity that could cause damage through sudden stopping of the hoisting machinery. A minimum brake capacity of 125% of the torque developed during the hoisting operation at the point of brake application has been determined to be acceptable.

The minimum hoisting braking system should include one power control braking system (not mechanical or drag brake type) and two holding brakes. The holding brakes should be applied when power is off and should be automatically applied on overspeed to the full holding position if a malfunction occurs. Each holding brake should have a torque rating not less than 125% of the full-load hoisting torque at point of application (location of the brake in the mechanical drive). The minimum number of braking systems that should be operable for emergency lowering after a single brake failure should be two holding brakes for stopping and controlling drum rotation.

The holding brake system should be single failure proof; i.e., any component or gear train should be dual if interposed between the holding brakes and the hoisting drums. The dynamic and static alignment of all hoisting machinery\components, including gearing, shafting, couplings, and bearings, should be maintained throughout the range of loads to be lifted, with all components positioned and anchored on the trolley machinery platform.

Manual operation of the hoisting brakes may be necessary during an emergency condition, and provision for this should be included in the design conditions. Adequate heat dissipation from the brake should be ensured so that damage does not occur if the lowering velocity is permitted to increase excessively. It may be necessary to stop the lowering operation periodically to prevent overheating and permit the brake to dissipate the excess heat.

Portable instruments should be used to indicate the lowering speed during emergency operations. If a malfunction of a holding brake were to occur and emergency lowering of the load become necessary, the holding brake should be restored to working condition before any lowering is started.

5. BRIDGE AND TROLLEY

5.1 Braking Capacity

Failure of the bridge and trolley travel to stop when power is shut off could result in uncontrolled incidents. This would be prevented if both bridge and trolley drives are provided with control and holding braking systems that would be automatically applied when the power is shut off or if an overspeed or overload condition occurs because of malfunction or failure in the drive system.

To avoid the possibility of drive motor overtorque within the control system, the maximum torque capability of the driving motor and gear reducer for trolley motion and bridge motion of the overhead bridge crane should not exceed the capability of gear train and brakes to stop the trolley or bridge from the maximum speed with the DRL attached. Incremental or fractional inch movements, when required, should be provided by such items as variable speed controls or inching motor drives. Control and holding brakes should each be rated at 100% of maximum drive torque that can be developed at the point of application. If two mechanical brakes, one for control and one for holding, are provided, they should be adjusted with one brake in each system leading the other and should be activated by release or shutoff of power. This applies to both trolley and bridge. The brakes should also be mechanically tripped to the "on" or "holding" position in the event of a malfunction in the power supply or an overspeed condition. Provisions should be made for manual emergency operation of the brakes. The holding brake should be designed so that it cannot be used as a foot-operated slowdown brake. Drag brakes should not be used. Mechanical drag-type brakes are subject to excessive wear, and the need for frequent service and repair tends to make this type of brake less reliable; they should therefore not be used to control movements of the bridge and trolley.

Opposite-driven wheels on bridge or trolley that support bridge or trolley on their runways should be matched and should have identical diameters.

Trolley and bridge speed should be limited. The speed limits indicated for slow operating speeds for trolley and bridge in specification CMAA #70 are recommended for handling MCLs.

5.2 Safety Stop

Limiting devices, mechanical and/or electrical, should be provided to control or prevent overtravel and overspeed of the trolley and bridge. Buffers for bridge and trolley travel should be included at the end of the rails.

Safety devices such as limit-type switches provided for malfunction, inadvertent operator action, or failure should be in addition to and separate from the limiting means or control devices provided for operation.

6. DRIVERS AND CONTROLS

6.1 Driver Selection

The horsepower rating of the hoist driving motor should be matched with the calculated requirement that includes the design load and acceleration to the design hoisting speed. Overpowering of the hoisting equipment would impose additional strain on the machinery and load-carrying devices by increasing the hoisting acceleration rate.

To preclude excessive drive motor torque, the maximum torque capability of the electric motor drive for hoisting should not exceed the rating or capability of the individual components of the hoisting system required to hoist the MCL at the maximum design hoist speed. Overpower and-overspeed conditions should be considered an operating hazard as they may increase the hazard of malfunction or inadvertent operation. It is essential that the controls be capable of stopping the hoisting movement within amounts of movement that damage would not occur. A maximum hoisting movement of 8 cm (3 in) would be an acceptable stopping distance.

Normally, a crane system is equipped with mechanical and electrical limiting devices to shut off power to driving motors when the crane hook approaches the end of travel or when other parts of the crane system would be damaged if power were not shut off. It is prudent to include safety devices in the control system for the crane, in addition to the limiting devices, for the purpose of ensuring that the controls will return to or maintain a safe holding position-in case of malfunction. Electric circuitry design should be carefully considered so that the controls and safety devices ensure safe holding of the critical load when called upon to perform their safety function. For elaborate control systems, radio control, or ultimate control under unforeseen conditions of distress, an "eme~rgency stop button" should be placed at ground level to remove power from the crane independently of the crane controls. For cranes with a DRL rating much higher than the MCL rating, it may be necessary to provide electrical or mechanical resetting of overload sensing devices when changing from one operation to the other. Such resetting should be made away from the operator cab location and should be included in an administrative control program.

6.2 Driver Control Systems

The control systems should be designed as a combination of electrical and mechanical systems and may include such items as contactors, relays, resistors, and thyristors in combination with mechanical devices and mechanical braking systems. The control system(s) provided should include consideration of the hoisting (raising and lowering) of all loads, including the rated load, and the effects of the inertia of the rotating hoisting machinery such as motor armature, shafting and coupling, gear reducer, and drum. If the crane is to be used for lifting spent fuel elements, the control system should be adaptable to include interlocks that will prevent trolley and bridge movements while the load is being hoisted free of a reactor vessel or a storage rack, as may be recommended in Regulatory Guide 1.13, "Spent Fuel Storage Facility Design Basis."

6.3 Malfunction Protection

Means should be provided in the motor control circuits to sense and respond to such items as excessive electric current, excessive motor temperature, overspeed, overload, and overtravel. Controls should be provided to absorb the kinetic energy of the rotating machinery and stop the hoisting movement reliably and safely through a combination of electrical power controls and mechanical braking systems and torque controls if one rope or one of the dual reeving systems should fail or if overloading or an overspeed condition should occur.

6.4 Slow Speed Drives

Increment drives for hoisting may be provided by stepless controls or inching motor drive. If jogging or plugging is to be used, the control circuit should include features to prevent abrupt change in motion. Drift point[10] in the electric power system when provided for bridge or trolley movement should be provided only for the lowest operating speeds.

6.5 Safety Devices

Safety devices such as limit-type switches provided for malfunction, inadvertent operator action, or failure should be in addition to and separate from the limiting means or control devices provided for operation.

6.6 Control Stations

The complete operating control system and provisions for emergency controls for the overhead crane handling system should preferably be located in a cab on the bridge. When additional operator stations are considered, they should have control systems similar to the main station. Manual controls for hoisting and trolley movement may be provided on the trolley. Manual controls for the bridge may be located on the bridge. Remote control or pendant control for any of these motions should be identical to those provided on the bridge cab control panel. Cranes that use more than one control station should be provided with electrical interlocks that permit only one control station to be operable at any one time. In the design of the control systems, provision for and locations of devices for control during emergency conditions should be provided.

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[10] Drift point is a point in the lowest range of movement control at which power is on, brakes are off, and motors are not energized.

7. INSTALLATION INSTRUCTIONS

7.1 General

Installation instructions should be provided by-the manufacturer. These should include a full explanation of the crane handling system, its controls, and the limitations for the system and should cover the requirements for installation, testing, and preparations for operation.

7.2 Construction and Operating Periods

When the permanent plant crane is to be used for construction and the operating requirements for construction are more severe than those required for permanent plant service, the construction operating requirements should be defined separately. The crane should be designed structurally and mechanically for the construction loads, plant service loads, and their functional performance requirements. At the end of the construction period, the crane handling system should be modified as needed for the performance requirements of the nuclear power plant operating service. After construction use, the crane should be thoroughly inspected by nondestructive examination and load tested for the operating phase. The extent of nondestructive examination, the procedures used, and the acceptance criteria should be defined in the design specification. If allowable design stress limits for the plant operating service are to be exceeded during the construction phase, added inspection supplementing that described in Section 2.6 should be specified and developed.

During and after installation of the crane, the proper assembly of electrical and structural components should be verified. The integrity of all control, operating, and safety systems should be verified as to satisfaction of installation and design requirements.

8. TESTING AND PREVENTIVE MAINTENANCE

8.1 General

A complete check should be made of all the crane's mechanical and electrical systems to verify the proper installation and to prepare the crane for testing.

Information concerning proof testing on components and subsystems that was required and performed at the manufacturer' ' s plant to verify the ability of components or subsystems to perform should be available for the checking and testing performed at the place of installation of the crane system.

8.2 Static and Dynamic Load Tests

The crane system should be static load tested at 125% of the MCL. The tests should include all positions generating maximum strain in the bridge and trolley structures and other positions as recommended by the designer and manufacturer. After satisfactory completion of the 125% static test and adjustments required as a result of the test, the crane handling system should be given full performance tests with 100% of the MCL for all speeds and motions for which the system is designed. This should include verifying all limiting and safety control devices. The features provided for manual lowering of the load and manual movement of the bridge and trolley during an emergency should be tested with the MCL attached to demonstrate the ability to function as intended.

8.3 Two-Block Test

When equipped with an energy-controlling device between the load and head blocks, the complete hoisting machinery should be allowed to two-block during the hoisting test (load block limit and safety devices are bypassed). This test, conducted at slow speed without load, should provide assurance of the integrity of the design, the equipment, the controls, and the overload protection devices. The test should demonstrate that the maximum torque that can be developed by the driving system, including the inertia of the rotating parts at the overtorque condition, will be absorbed or controlled during two-blocking or load hangup. The complete hoisting machinery should be tested for ability to sustain a load hangup condition by a test in which the load-block-attaching points are secured to a fixed anchor or an excessive load. The crane manufacturer may suggest additional or substitute test procedures that will ensure the proper functioning of protective overload devices.

8.4 Operational Tests

Operational tests of crane systems should be performed to verify the proper functioning of limit switches and other safety devices and the ability to perform as designed. However, special arrangements may have to be made to test overload and overspeed sensing devices.

8.5 Maintenance

After installation, equipment usually suffers degradation due to use and exposure. A certain degree of wear on such moving parts as wire ropes, gearing, bearings, and brakes will reduce the original design factors and the capacity of the equipment to handle the rated load. With good maintenance practice, degradation is not expected to exceed 15% of the design load rating, and periodic inspection coupled with a maintenance program should ensure that the crane is restored to the design condition if such degradation is found. Essentially, the MCL rating of the crane should be established as the rated load capacity, and the design rating for the degradable portion of the handling system should be identified to obtain the margin available for the maintenance program. The MCL should be plainly marked on each side of the crane for each hoisting unit. It is recommended that the critical-load-handling cranes should be continuously maintained above MCL capacity.

9. OPERATING MANUAL

The crane designer and crane manufacturer should provide a manual of information and procedures for use-in checking, testing, and operating the crane. The manual should also describe a preventive maintenance program based on the approved test results and information obtained during the testing. It should include such items as servicing, repair and replacement requirements, visual examinations, inspections, checking, measurements, problem diagnosis, nondestructive examination, crane performance testing, and special instructions.

The operating requirements for all travel movements (vertical and horizontal movements or rotation, singly or in combination) incorporated in the design for permanent plant cranes should be clearly defined in the operating manual for hoisting and for trolley and bridge travel. The designer should establish the MCL rating and the margin for degradation of wear-susceptible component parts.

10. QUALITY ASSURANCE

Although crane handling systems for critical loads are not required for the direct operation of a nuclear power plant, the nature of their function makes it necessary to ensure that the desired quality level is attained. A quality assurance program should be established to the extent necessary to include the recommendations of this report for the design, fabrication, installation, testing, and operation of crane handling systems for safe handling of critical loads.

In addition to the quality assurance program established for site assembly, installation, and testing of the crane, applicable procurement documents should require the crane manufacturer to provide a quality assurance program consistent with the pertinent provisions of Regulatory Guide 1.28, "Quality Assurance Program Requirements (Design and Construction)," to the extent necessary.

The program should address all the recommendations in this report. Also included should be qualification requirements for crane operators.

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16. ABSTRACT (200 *words or less*)

NRC has licensed reactors on the basis that the safe handling of critical loads can be accomplished by adding safety features to the handling equipment, by adding special features to the structures and areas over which the critical load is carried, or by combination of the two. When reliance for the safe handling of critical system itself, the system should be designed so that a single failure will not result in the loss of the capability of the system to safely retain the load. This report identifies features of the design, fabrication, installation, inspection, testing, and operation of single-failure-proof overhead crane handling systems that are used for handling critical loads. These features are limited to the hoisting system and to braking systems for trolley and bridge. Other load-bearing items such as girders should be conservatively designed but need not be considered single failure proof.

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