Enclosure 4

EDR-1-NP, "eXtra Safety And Monitoring (X-SAM®) Single Failure Proof Cranes," Revision 7 (Non-Proprietary)

GENERIC LICENSING TOPICAL REPORT
EDR-1-NP

Westinghouse
eXtra Safety And Monitoring
(X-SAM®)
Single Failure Proof
CRANES

NON-PROPRIETARY VERSION

Notice

This revision of EDR-1 supersedes all previous revisions.

REVISION 7

5/4/15

AMENDMENT 7

NOTICE

This report was prepared by Ederer Incorporated (Ederer), with assistance from Holloran & Associates, for the use of Ederer. Its use by others is permitted only on the understanding that there are no representations or warranties, express or implied, as to the validity of the information or conclusions contained herein.

Revision 4 was prepared by PaR Nuclear, a Westinghouse Electric Company, current owners of the X-SAM® single failure proof technology and sole proprietor of EDR-1 Revision 4, Generic Licensing Topical Report. For historical references, actions referred to within this report prior to 2006, will collectively note Ederer Corporation (Ederer) as the responsible legal entity who performed those actions.

Revision 5 was prepared by Westinghouse Electric Company, current owners of the X-SAM® single failure proof technology and sole proprietor of EDR-1 Revision 5, Generic Licensing Topical Report. All figures and diagrams contained within this revision are intended to supersede their previously accepted version found in EDR-1 REV 3. Clarifying information was added to identify items and components referenced more clearly. Notes were added to select figures to reflect these as representative of typical X-SAM and X-SAM system designs. Non-Destructive Acceptance (NDA) techniques and practices were revised to allow for modern alternatives that will achieve the same level in of inspection and qualification integrity in a cost effective manner.

Revision 6 was prepared by Westinghouse Electric Company, current owners of the X-SAM® single failure proof technology and sole proprietor of EDR-1 Revision 5, Generic Licensing Topical Report. All figures and diagrams contained within this revision are intended to supersede their previously accepted version found in EDR-1 REV 3. Errata were corrected and the company name Ederer was replaced with Westinghouse where information didn't reflect historical accounts or actions.

Revision 7 was prepared by Westinghouse Electric Company, current owners of the X-SAM® single failure proof technology and sole proprietor of EDR-1 Revision 6, Generic Licensing Topical Report. All figures and diagrams contained within this revision are intended to supersede their previously accepted version found in EDR-1 REV 3. Clarifications to the hydraulic equalization systems were incorporated to provide a more comprehensive and representative configuration of the hydraulic equalizer schematics and arrangements.

ABSTRACT

Westinghouse's eXtra-Safety And Monitoring (X-SAM) Cranes and Compact Hoists are designed for a wide range of single-failure-proof overhead handling equipment applications in nuclear power plants. This report provides generic descriptions of the safety systems and components of X-SAM Cranes and Compact Hoists that are utilized to meet the guidance originally promulgated in Regulatory Guide 1.104, "Single-Failure-Proof Overhead Crane Handling Systems for Nuclear Power Plants" and more recently in NUREG 0554 "Single-Failure-Proof Cranes for Nuclear Power Plants."

A single-failure-analysis of the reference design X-SAM trolley for installation on an existing crane bridge is included. Typical design data is provided for cranes and hoists of the reference design that range in capacity from 10 Tons to 250 Tons. Throughout the EDR-1 document, 'typical' design data, figures, charts, tables, and the associated information contained within, are intended to convey the overarching design methodology, characteristics, elements, features, and or configurations applicable to an EDR-1 single failure proof crane. This 'typical information is not intended to be interrupted as bounding or limited to the exact data, arrangements, or conditions shown, so as long as the same methodology, formulas, equations, features and functionality are maintained or exceeded by design. As EDR-1 is intended to be a generic licensing document, each particular application will be specifically tailored for that applicant's particular geometry or functional parameters using these basic design principles & concepts found within these associated 'typical' denotations. As individual application parameters change, component technology advances, and or OEM component sourcing changes, these conditions will still continue to reflect the 'typical' design methodology, characteristics, elements, features, and or configurations depicted. Compliance with the applicable regulatory guidance and the provisions for operational testing of the hoist safety systems are also described.

Design of the girder structure is highly dependent upon site and plant specific seismic parameters. Therefore, girder design is dealt with in licensing documents for specific plants.

The original authored document of EDR-1, Ederer Cranes and their associated technical representatives responsible for the design of the X-SAM single failure proof system and generation of the generic licensing topical report to be within compliance of the requirements documented in NUREG 0554, coined the terminology 'Nuclear Safety Related' (NSR) within the Generic Licensing Topical Report. The intention of this NSR terminology and component/system designation was meant to identify the "important to safety" aspect of the component /system in the critical load handling environment at nuclear facilities. This designation would establish the system or component of the X-SAM design, as a Critical Item (CI), for an augmented quality classification with the single failure proof design. These components or systems would be then subject to the defined examinations and testing established within Appendix A of EDR-1 Generic Licensing Topical Report specifically to comply with NUREG 0554. Absent from NUREG 0554 are the design requirements or language that mandate the designation of particular items, components, or systems as safety-related or basic components. Ultimately, this functional definition and classification solely falls on the systems Architect/Engineer and or nuclear facilities licensee depending on that particular application.

Given the close representation of this coined phrase 'Nuclear Safety Related' (NSR) to the similarly expressed safety-related component/system (basic component) in the nuclear application environment, over the years an evolution of conservative nuclear culture had conflated these terms to form a singular synonymous meaning solely associated with a safety-related component/system. For this reason, the terminology 'Nuclear Safety Related' (NSR) has been removed from the EDR-1 topical report. The original use and identification of components within EDR-1 as NSR, was never meant to designate a component as a Safety-Related item in terms of a system, structure, component, and or control that is relied upon to remain functional during and following design-basis events. This would include any such identification, within the topical report itself for the application of a single failure proof crane within a nuclear facility, as having the function necessary to maintain the integrity of the reactor coolant pressure boundary, nor the capability to shut down the reactor and maintain it in a safe shutdown condition, nor have the capability to prevent or mitigate the consequences of accidents which could result in unacceptable offsite radiation exposures.

Table of Contents and Revision Summary

Table of Contents and Revision Summary (cont.)

Note:

Not all of the reference design hoists depicted in these figures are of the same capacity. Therefore, some of the design details and arrangements shown will not always be consistent between figures.

Table of Contents and Revision Summary (cont.)

Table of Contents and Revision Summary (cont.)

Summary of changes to the generic licensing topical report for X-SAM single failure proof cranes and hoists

1. Diagrams, figures, examples and tables were re-titled to represent "typical" X-SAM system configurations. This will allow for further consistency throughout the generic licensing topical report.

Below are the associated revised figures and their corresponding modifications:

- Figure III.C.1.d.1 – Component Identification notation
- Figure III.C1.d.2 – Allowance for alternative NDA techniques
- Figure III.D.3.a – Designation of Typical X-SAM and X-SAM system designs
- Figure III.D.3.b – Designation of Typical X-SAM and X-SAM system designs
- Figure III.D.3.c – Designation of Typical X-SAM and X-SAM system designs
- Figure III.D.5 – Designation of Typical X-SAM and X-SAM system designs
- Figure III.D.6 – Component Identification with associated reference to Appendix A

2. Examples and tables were updated to reflect current technology and non-destructive examination standards and criteria. These updates closer align EDR-1 with accepted industry standards that are compliant with NUREG 0554.

   Table III.F.I has revisions to provide the appropriate correlation to modern technology and the corresponding industry terminology and classification for these components. Identification of variable frequency flux vector drives were denoted to represent the modern state-of-the art controls that can be used on cranes of this design. Also included in the revision of this table is the designation of dynamic lowering as an additional alterative in the control braking category. Lastly, changes were made to the rope classification to reflect modern industrial naming conventions. This is reflected in the revised notation of the 6x36 IWRC classification of the wire rope which includes the previously identified 6x37 IWRC type of wire rope in this family of wire class designation.

3. Appendices A, B, and C were reformatted for ease of use, understanding and implementation in licensing applications. All appendices received general makeover to incorporate a tabular format. This revision provides access to a modern electronic version so that the necessary licensing crane information can be easily input with the allowance and flexibility to expand as necessary for any additional notation or specification of crane data to the associated regulatory categories. Appendix A required a more comprehensive revision to the information, which is outlined in the paragraph below.

   Appendix A is intended to supersede all previously accepted versions found in EDR-1. Items, components and systems within this appendix are therefore identified as 'Critical Items' and subject to the specified augmented quality requirements, tests, and certifications established in the generic licensing topical report. Application of these augmented quality requirements will fall under an approved 10CFR50 Appendix B quality program when utilized for use at a nuclear facility. Removed from this appendix is the NSR designation and associated notes to avoid future misinterpretation of these components and or system classifications. Additionally, NDA terminology has been updated to reflect modern terminology designations, standards, and allowances for alternative NDA techniques and practices. In instances where alternative NDA methodology has been established to qualify components, these alternative NDA testing methods, at a minimum, will offer the same level of quality assurance and component integrity validation as the original NDA requirement. These alternative NDA techniques allow for more economical methods to be pursued.

4. Improve the alignment of EDR-1 with the established requirements of NUREG 0554 and clearly define the intended identification of Critical Item components, systems, and operations within the X-SAM single failure proof design. This includes the removal of all 'Nuclear Safety Related' (NSR) terminology used throughout the generic topical report from its inception to its Revision 3 acceptance by the NRC in 1983.

I. INTRODUCTION

References A and B allow applicants to provide safe handling of critical loads by making the overhead crane handling system "single-failure-proof", rather than by adding special features to the structures and areas over which critical loads are carried. Regulatory Guide 1.104 and its successor, NUREG-0554, describe an acceptable approach to making an overhead crane handling system "single-failure-proof." This document is the Generic Licensing Topical Report for Westinghouse's eXtra-Safety And Monitoring (X-SAM) Hoisting System, which is Westinghouse's way of complying with Regulatory Guide 1.104 and NUREG-0554.

Westinghouse's "Job Engineered" X-SAM Cranes represented a substantial advancement in the state of the art of design and manufacture of "single-failure-proof" hoists. This breakthrough in hoist safety and monitoring systems allowed a single drive train hoist to be "single-failure-proof", for the first time.

The Hoist's Integrated Protective System (HIPS)® lies at the heart of all X-.SAM Cranes. HIPS gives X-SAM Hoists the capability of reporting abuse, in addition to their inherent protection against damage. The monitoring features of HIPS allow the X-SAM Cranes to be conservatively designed, without massive duplication or oversizing of hardware. Thus, Westinghouse's X-SAM Cranes can accommodate more abuse, without damage, than comparable capacity conventional cranes and hoists. Certain of the HIPS monitoring systems report abuse resulting from operator errors and component failures, to allow management the prerogative of corrective action. Thereby, recurrence of incidents, which would have resulted in failure or degradation of critical components in conventional cranes and hoists, are minimized.

Most of the important safety features of X-SAM Cranes can be retrofitted on existing cranes, either by a complete replacement of the trolley or by replacing selected hoisting machinery components. The substantive safety features of HIPS are particularly important in retrofit applications, since they protect existing structural components, whose quality and margin of safety may not be fully documented, from overloads throughout their life. The inherent safety available with HIPS also gives Westinghouse greater flexibility in meeting Regulatory Guide 1.104's "single-failure-proof" criteria, within previously established facility space and weight restrictions.

Subsequent to NRC acceptance of Revision 2 of this topical report, the design of the HIPS has evolved to the point where compact hoists with the features of X-SAM Cranes are now practical. Previously, low capacity (10 to 20 Ton) X-SAM hoists were simply smaller versions of the high capacity (50 to 250 Ton) X-SAM hoists. The size and arrangement of these low capacity hoists restricted their application to auxiliary hoists on overhead crane trolleys. However, most nuclear power facilities have compact -low capacity (I to 20 Ton) hoists in areas that are not served by overhead cranes, e.g., underhung monorail hoists. Evaluations performed in accordance with Reference A have revealed situations where such hoists must carry critical loads. However, most compact hoists are produced as off-the-shelf hardware in large quantities, without the quality and design features required by the Regulatory Guide 1.104. So, single-failure-proof low capacity compact hoists have not been commercially available. Therefore, Westinghouse has developed Compact X-SAM Hoists that have essentially the same design features as the hoists in X-SAM Cranes. The physical arrangement of the Compact X-SAM Hoists' components has been varied to provide the compact package needed for this application. Throughout this report references to X-SAM Cranes and Hoists also apply to Compact X-SAM Hoists, unless otherwise indicated.

A. Purpose

This report has two purposes:

4. Generic licensing of X-SAM Hoisting Systems for use in existing facilities.
5. Extention of this generic licensing to complete X-SAM Cranes for new facilities.

B. Scope

6. This report describes the reference designs:
   - Special hoist safety systems and components;
   - Compliance with the applicable regulatory positions;
   - Operational test provisions;
   - Single-failure-analysis; and
   - Envelope of design characteristics, including those of complete cranes for new facilities.
7. The generic issues involved in licensing a "single-failure-proof" hoisting system in accordance with Regulatory Guide 1.104 are addressed. The only actions required to retrofit an X-SAM Hoisting System in an existing facility involve:
   - Sizing and arranging the hoist components;
   - Ascertaining compliance with the report's generic design bases;
   - Evaluating the acceptability of the components and structures that are not replaced; and
   - Verifying that the plant design will safely accommodate the limited, controlled load motion following a single cable failure or a drive train component failure during hoisting and lowering operations.
8. Appendices B and C summarize the plant specific information that is needed to complete licensing of a retrofit X-SAM Hoisting System.
9. The generic information regarding the X-SAM Hoisting System is equally applicable to complete nw cranes and hoists. The only additional actions necessary to incorporate a complete X-SAM Crane or Compact X-SAM Hoist in a new facility design are:
   - Developing the detailed girder or monorail design to support the trolley or hoist; and
   - Performing the requisite structural and seismic analyses of the girder or monorail design.

C. Applicability

This report, being generic in nature, is intended to apply to all types of nuclear facilities requiring "single-failure-proof" overhead handling equipment, as defined by Regulatory Guide 1.104 and NUREG-0554.

D. History and Background

Ederer is a pioneer supplier of dual load path hoists. It all started, many years ago, with one of the first dual load path hoists ever built for a nuclear power plant-the reactor crane for TVA's Browns Ferry Station. In the ensuing

years Ederer refined the design of the Browns Ferry crane into its second generation of dual load path hoists. In 1976 Northern States Power selected Ederer to design and build the replacement trolley for Monticello's Cask Handling Crane, which was one of the first cranes licensed under Revision 0 of Regulatory Guide 1.104. Reference C, as revised by Reference D, describes the Monticello Crane. The NRC approved use of this crane for making lifts, with certain restrictions, in Reference E.

Based upon the lessons learned from the design, manufacture, and licensing of Monticello's dual load path trolley, Ederer established the ambitious research and development program that has already led to HIPS and X-SAM Cranes and Compact Hoists.

Ederer's first two "X-SAM" Hoists with the new HIPS are installed in the new trolley for the Loss of Fluid Test (LOFT) Containment Building Polar Crane. Both the 50 Ton Main Hoist and the 10 Ton Auxiliary Hoist incorporated HIPS. The new LOFT trolley fits within the same space and operating envelopes as the original 25-year-old trolley, which was of a conventional design. Appendix D summarizes the "lessons learned" from this retrofitting.

The X-SAM hoisting system has a wide variety of applications in both existing nuclear power plants and new facilities, including cask handling cranes, containment building polar cranes, and auxiliary and compact hoists for use when the critical loads are smaller than casks and reactor vessel heads.

II. REFERENCES

A. NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants"

B. Regulatory Guide 1.13, "Spent Fuel Storage Facility Design Basis"

C. "Redundant Design Feature Modifications and Safety Evaluation for the Reactor Building Crane System at the Monticello Nuclear Generating Plant," Licensing Report NSC-LS&R-NOR-O 151-17, dated November II, 1976, Docket No. 50-263

D. "Northern States Power letter to Mr. Dennis L. Ziemann, Chief Operating Reactors Branch 112, Division of Operating Reactors, U.S. N.R.C., dated February 28, 1977, which submitted revisions to NSC-LS&R-NOR-0151-17, Docket No. 50-263

E. NRC letter to Northern States Power, dated May 19, 1977, Docket No. 50-263

F. Crane Manufacturers Association of America (CMAA), Specification #70, "Specification for Electric Overhead Traveling Cranes"

G. ANSI N42. 7/IEEE Standard 279, "Criteria for Protection Systems for Nuclear Power Generating Stations"

H. IEEE Standard 323, "Standard for Qualifying Class I Equipment for Nuclear Power Generating Stations"

III. BODY OF REPORT

E. Description of How the Safety Systems Operate as an Integrated System

X-SAM Hoists utilize three types of safety systems for protection against equipment malfunctions and operator errors:

- Conventional hoist safety systems
- The new Hoist's Integrated Protective System (HIPS)
- The Balanced Dual Reeving System

The conventional hoist safety systems in Westinghouse's X-SAM Hoists include the usual upper and lower travel limits; overload sensing devices; hoist control protective features; and a holding brake on the high speed shafting. By preventing the incidents that cause overloads from occurring, these systems provide X-SAM Hoists their first line of defense against overloads. The conventional holding brake on the high speed portion of drive train holds the load during normal operations. Hoisting and load control are provided by hoist duty electric motors and controls.

Such standard protective devices cannot provide protection from the forces generated if a malfunction allows a two blocking, load hangup, or similar abuse, to occur. So conventional hoists, protected only by limit switches, load cells, etc., must absorb the forces of two blocking, load hangup, or similar abuse, in deflection or yielding of their load bearing components and structural supports. The typically large design margins in overhead crane structures and machinery allow them to forgive many abuses. However, once these margins are exhausted, either by accumulation of minor abuses or a single serious incident, a conventional crane can fail catastrophically without warning.

Normally, it is impossible to verify, throughout the life of a crane, that unreported two blockings, overloads, or other abuses have not previously occurred. Therefore, unless the consequences of such incidents are controlled, the factor of safety of certain components will almost always be suspect.

HIPS provides X-SAM Hoists a second line of defense. HIPS prevents overload of hoist components even if incidents occur that would have caused overloads in conventional hoists. HIPS also protects against other types of incidents, such as improper wire rope spooling, to which conventional hoists are vulnerable. In addition, HIP-S provides an independent, emergency path for stopping and holding the load in the event of any single, credible failure in the hoist drive train.

As shown in Figure III.A, HIPS includes a special Emergency Drum Brake System that acts on the wire rope drum, a Failure Detection System, and an Energy Absorbing Torque Limiter (EATL) in the drive train. The Failure Detection System actuates the Emergency Drum Brake System-stopping the wire rope drum if a drive train discontinuity or component failure occurs.

The EATL allows the hoist to safely withstand two blocking[1], load hangup[2], or other overloading event and still retain the load, even if the drive motor is not de-energized. Not only are the loads controlled following these overloads, but the hoist's components are also protected, throughout their life, from being overstressed by these incidents. To provide this protection, the EATL directly converts the hoists' high speed kinetic energy to heat during an overloading incident.

The Balanced Dual Reeving System protects against loss of the load and load sway in the event of a single cable failure. In achieving this capability, the system is balanced in a unique, yet simple, way that protects the wire rope from being cut or crushed if the upper limit switches fail – allowing the lower block to contact the trolley structure. This feature permits X-SAM Hoists to also utilize the wire rope's inherent energy absorbing capability in withstanding two blockings. The Hydraulic Load Equalization System limits load motion following a cable failure. The Failure Detection System is also actuated in the event of a cable failure.

Another safety feature of all X-SAM Hoists is the emergency lowering capability afforded by the Emergency Drum Brake System. It is not necessary to frequently stop the lowering of the load to allow the brakes to cool, as is required if only conventional high speed holding brakes are used. The Emergency Drum Brake System allows lowering of the design rated load continuously from the maximum hook height without exceeding the temperature limits of the brakes. The emergency load lowering capability provided by the Drum Brake System is in addition to the conventional emergency method, which relies upon the hoist's high speed holding brakes.

1. Two blocking – Continued hoisting in which the load block and head block assemblies are brought into physical contact, thereby preventing further movement of the load block.
2. Load hangup – Abrupt stopping of the load or load block during hoisting by entanglement with fixed objects.

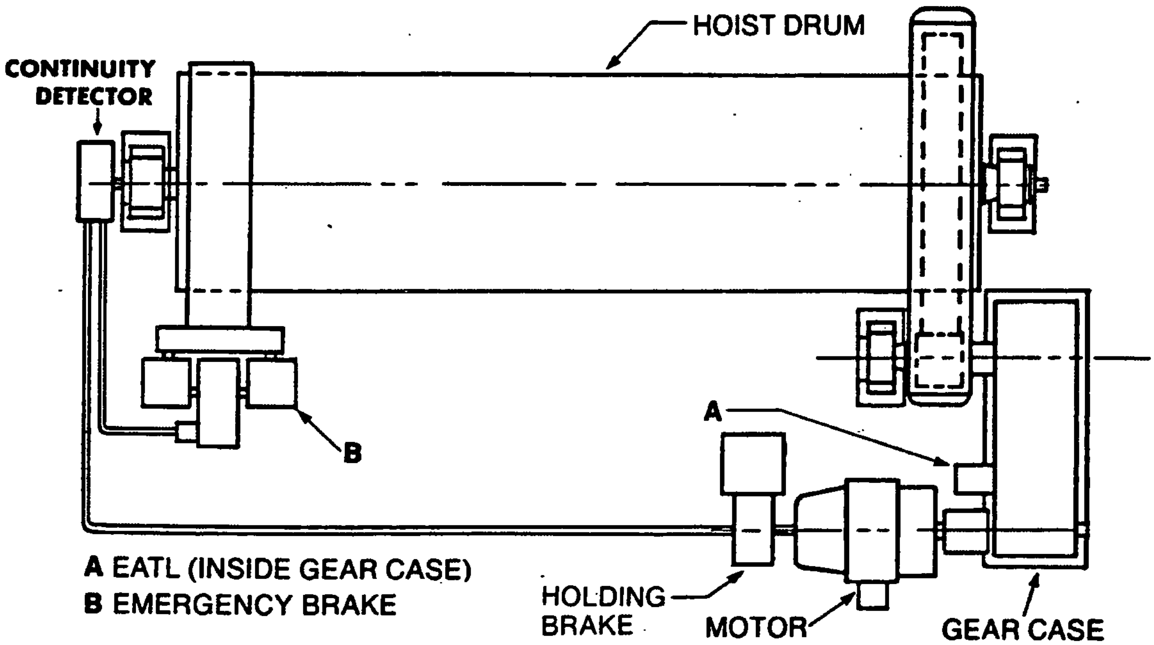


Figure III.A
Typical X-SAM Crane Hoist Arrangement

F. Crane Safety System Descriptions

This section describes the various safety features of Westinghouse's reference design X-SAM Hoists.

1. Hoists' Integrated Protective System (HIPS)

HIPS is a series of special hoist safety systems, and subsystems, which have been integrated to:

- Monitor abuse of the crane or compact hoist.
- Limit the amount of abuse to which the crane or compact hoist can be subjected.
- Protect the crane or compact hoist against the consequences of an abnormally large amount of abuse.
- Report abuse of the crane or compact hoist so that management can take action to prevent its recurrence.

The systems that make up HIPS include:

a. Energy Absorbing Torque Limiter (EATL) – The EATL is incorporated in the hoist gear case and acts both as an energy absorber and a torque limiter. Under normal loading conditions, the EATL functions as a standard gear in transmitting the drive motor's power. During load hangup, two blocking, or overload, the EATL limits the maximum load imposed on the reeving system, while dissipating the rotational kinetic energy of the high speed components. Even while it is absorbing the rotational kinetic energy, the EATL continues to transmit sufficient torque to hold the load. The EATL automatically resets mechanically and needs no special maintenance other than periodic checks of the torque limit setting. Because of the line pull during load hangup, two blocking or overload has been limited, the crane or compact hoist can be promptly returned to service, as soon as the cause of the incident has been identified and corrected. Replacement of components following a two blocking, etc., is not required, since the stress levels have not exceeded known, acceptable values. Further information regarding the EATL is contained in Section D.

b. Emergency Drum Brake System – The Emergency Drum Brake System is activated by the Failure Detection System. This system provides an independent means for reliably and safely stopping and holding the load following a failure in the hoist machinery. The brake is released by an externally supplied force and needs no externally supplied force for actuation, to provide fail safe operation.

   The Emergency Drum Brake System normally will not set during the normal duty cycle.

   A manual control station is located on the trolley deck. It allows safe lowering of the load without electrical power in an emergency. The Emergency Drum Brake is described in Section D.

c. Failure Detection System – The primary function of the Failure Detection System is to detect a loss of mechanical continuity in the hoist machinery and, when necessary, detect actuation of the EATL. Secondarily, its detectors sense improper rope spooling, reeving continuity, and drum overspeed.

   An error in any of the above parameters results in shutdown of the crane hoist machinery and setting of the Emergency Drum Brake System after the load lowers a small amount. The key to a locked control panel or key operated switch is required to reset the Failure Detection System. Both the crane control relays and the Emergency Drum Brake System require electrical power to remain in their normal operating mode. The Failure Detection System removes the electrical power when an error is sensed. Therefore, loss of electrical power results in the same action as an error signal, although a key is not required to start the crane after power is restored.

   Provisions for detecting main hoist drum overspeed are included, since drum overspeed can occur only if there has been a control malfunction or a mechanical failure in the drive train. Mechanical continuity is also sensed by monitoring the differential in motor and drum shaft rotation after compensating for the gear train ratio. This method also detects actuation of the EATL. Section D describes the Drive Train Continuity Detector.

The Wire Rope Spooling Monitor is an electro-mechanical assembly that senses improper spooling caused by misuse of the crane, such as excessive side pull or off center lifts. Improper spooling is sensed prior to cable damage. However, the possible catastrophic consequences of damaged cables dictate that the Failure Detection System be actuated, if improper spooling occurs.

d. Drum Safety Structure – Retention of the drum on the trolley, in case of drum shaft or support bearing failure, is provided by the Drum Safety Structure. The Drum Safety Structure design ensures that a shaft or bearing failure will not allow the drum to disengage from its drive gear or Emergency Drum Brake System. Section D describes the Drum Safety Structure Design.

e. Wire Rope Protection – The hoist is designed to withstand two blocking without mechanically damaging the wire rope. The hoist drum has sufficient grooving to accommodate the additional wire rope spooled in raising the lower block to the trolley load girt, without ropes crossing or chafing. The upper and lower block sheaves are arranged so that the wire rope does not contact the support structure, nor is it subjected to excessive fleet angles if a two blocking occurs. Further, the lower block is designed to mate with the load girt in such a manner that the lower block sheaves will not contact the load girt so they will remain free to rotate.

f. Emergency Stop Button – An emergency stop button at each control station removes power from the crane and sets the Emergency Drum Brake System as soon as the load starts to lower.

2. Conventional Hoist Safety Systems

X-SAM hoists also have the hoist safety systems that are commonly installed on conventional overhead cranes and compact hoists. HIPS protects against the consequences of misoperation of these conventional safety systems, as well as operator abuses and component failures.

a. Dual Upper Limit Switches – Two separate and independent limit switches sequentially actuate as the load block reaches its upper limit of travel. The primary, rotary limit switch on the drum shaft senses both the upper and lower positions of load block travel. The primary upper limit switch de-energizes the hoist controls.

   If the hoisting motion is not stopped by the rotary limit switch, a secondary, lever operated, limit switch is tripped by the lower block. The secondary switch actuates the Failure Detection System, since it can be tripped only if there has been a primary limit switch or control system failure. The Failure Detection System sets the Emergency Drum Brake, which removes all power from the hoist. A phase reversal relay is provided when necessary to ensure the proper functioning of the hoist and travel limits, including those of non-XSAM hoists that are installed with X-SAM hoists on the same bridge.

b. Overload Sensing and Indication – A load cell is installed in the hoist reeving. Exceeding the load limit setting shuts down the hoist, but does not actuate the Failure Detection System. The load cell senses overloads that result from two blocking or load hangup – de-energizing the hoist controls, and setting the conventional holding brakes on the high speed shafting.

c. Load Control System – Conventional crane control systems are provided to suit the needs of the applicant. The HIPS protects against the consequences of control system malfunctions, so most aspects of the X-SAM Cranes' control systems do not have to be "single-failure-proof."

d. High Speed Holding Braking – Conventional high speed holding braking is provided on the high speed shafting to hold the load during normal operations. Redundancy in the high speed holding braking is not required since the Emergency Drum Brake provides single failure proof braking.

3. Balanced Dual Reeving System

HIPS provides substantial protection of the reeving by preventing overloads and mechanical damage of the cables. The Balanced Dual Reeving System provides further protection against loss of the load in the event of a cable failure. It includes:

e. Dual Reeving – A standard reeving scheme has been modified to provide a balanced load path using two independent sets of reeving. Figure III.C.3.e shows the reeving arrangement of typical X-SAM Cranes. The number of parts of reeving per wire rope and the number of wire ropes per set of reeving are adjusted, along with the wire rope diameter and the number of drums, to suit the hoist's design rated capacity.

f. Hydraulic Load Equalization System – The dead ends of the two independent sets of reeving are attached to the Hydraulic Load Equalization System. This system allows equalization of the two sets of reeving during normal operations, but retards any sudden motion caused by a broken rope. The Hydraulic Load Equalization System is described in Section D.

g. Wire Rope – Each system is designed to withstand the peak static and dynamic loads imposed by a single wire rope failure, without exceeding 90% of the yield strength of the cable, with the allowance for cable wear and fatigue described in Section C (C.3.e) of this report.

G. Summary of Compliance With Regulatory Positions of Regulatory Guide 1.104

The regulatory positions of Revision I (Draft 3) of Regulatory Guide 1.104 have been addressed in the design of X-SAM Cranes. Additional information regarding compliance with, and exceptions to, certain of the regulatory positions is provided below. Appendices Band C identify the additional plant specific information that is needed to verify a specific retrofit crane's compliance with the Regulatory Positions.

Regulatory Position	Additional Information
C.1.a	X-SAM Cranes are designed to handle the rated load and may be used for construction loads up to this capacity. At no time should the cranes handle more than the design rated load. The applicant is responsible for establishing a conservative estimate of the projected construction total load spectrum and specifying crane duty classification compatible with the total of anticipated construction and operational usage. As a minimum all X-SAM Cranes and Hoists have a crane duty classification of A-I in accordance with Reference F.
C.1.b (1)	Closed box sections of crane structures located outside of containment may not be vented.
C.1.b (2)	Nil Ductility Transition Testing is performed in accordance with this regulatory position for load bearing structural members fabricated from rolled materials as indicated on the sample Critical Items List (Appendix A). The minimum operating temperature specified by the applicant is used to establish the acceptance criteria in accordance with this regulatory position.
C.1.b (3) C.1.b (4)	These regulatory positions are not applicable to complete new X-SAM Cranes since the testing recommended by C.I.b (2) is performed and low-alloy steel, such as ASTM` A514, is not used in X-SAM Cranes. The applicant is responsible for any required testing of existing crane structures and components when X-SAM hoisting systems are retrofitted.
C.1.c	Maximum stress levels under SSE seismic conditions in load bearing structures and machinery provided by Westinghouse are limited to 90% of the yield strength of the material, based upon the gross section of the member, excepting the wire rope. The maximum tension in the wire rope is limited to 77% of the published yield strength of the wire rope to provide an extra 15% margin for wire rope degradation.
C.1.d	Figures III.C.I.d.1 and III.C.I.d.2 identify the type of trolley and girder structural welds whose failure might result in the loss of a critical load. The sample Critical Items list (Appendix A) identifies the nondestructive examinations to be performed on welds and base material at weld joints.
C.1.e	Dynamic stress levels of critical structural and mechanical components, during projected usage, are kept below the endurance limit of the materials. Stress concentration factors are used in determining dynamic stresses.

Regulatory Position	Additional Information
C.1.f	Post weld heat treatment normally is provided only for welded gear cases. Additional post weld heat treatment of small weldments is also provided, e.g., hook trunnion, etc., when the materials joined are more than l 1/2 inches thick and the fillet, partial penetration or material repair welds used are more than 3/4 inches thick. Normally, it is possible to select material and weld thickness of the large weldments, e.g., girders, trolleys, etc., such that this criterion, which is consistent with Section III, Subarticle NF -4620, of the ASME Code, does not require their post weld heat treatment.
C.2.a	X-SAM Crane's automatic controls, limiting devices, and HIPS are designed so that, when disorders due to inadvertent operator action, component malfunction, or disarrangement of subsystem control functions occur singularly 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 is included at all control stations. This button removes power from the crane and sets the Emergency Drum Brake if the load starts to lower. Provisions for shutting the hoist down and setting the holding brake(s) are provided if needed so that the holding brake(s) will set upon loss of one phase of hoist power. Alternatively, analyses in accordance with Appendices E and/or I are performed to verify that load motion and kinetic energy will not exceed acceptable amounts following a loss of one phase of hoist power. The EATL, in combination with the Failure Detection System, protects the hoist and thus the load from a failure of the hoist motor control system to de-energize the motor when required. Furthermore, the Failure Detection System will actuate the Emergency Drum Brake upon a failure of the hoist motor control system to hold the load. Therefore, neither a single failure analysis or a Failure Modes and Effects Analysis of the hoist motor control system is necessary to ensure that any single failure in the hoist motor control system will not result in loss of a critical load.
C.2.b	The Failure Detection System and the Emergency Drum Brake System stop and hold the load in an immobile safe position in case of a subsystem or component failure. The analysis described by Appendix E is used to determine the maximum extent of load motion, following a drive train failure. The maximum kinetic energy of the load following a drive train failure is also determined. This information is provided to the applicant for use in verifying that the facility design will accommodate this limited controlled load motion. If necessary, provisions can be made for automatically actuating the Emergency Drum Brake prior to carrying the load over areas of the facility that the applicant determines cannot accommodate the amount of load motion that can follow a drive train failure.

Regulatory Position	Additional Information
C.2.c	The Emergency Drum Brake allows most repairs to the hoist to be made without lowering the load. The applicant is responsible for establishing safe load lay down areas for use in the event repairs to the crane are required that cannot be made with the load suspended. Provisions are made in the crane design for moving the crane to the designated lay down areas. The Emergency Drum Brake allows the load to be lowered to the lay down area without power.
C.2.d	Depending upon the location and application of the crane, it may not be possible to place the crane handling system back into service after component failure{s} with the reactor operating, e.g., the crane may be located in an "exclusion area" during reactor operations. The applicant is responsible for verifying that replacement crane components can be brought into the building/containment without an unacceptable release of radioactivity. The applicant is also responsible for verifying that an area is available where repair work can be accomplished on the crane without affecting the safe shut down capability of the reactor, i.e., a load drop associated with the crane repairs in this area will not damage equipment required to maintain the reactor in a safe shut down condition, or continued operation of the reactor if the applicant intends to operate the reactor during such repairs.
C.3.a	A single load path attaching point and lower block trunnion/sideplates are provided in the reference design in lieu of the two load attaching points specified by the regulatory position. X-SAM Cranes provide an equivalent margin of safety to that specified by providing the single load path parts with a capacity equal to or greater than the combined capacity specified for two attaching points. HIPS prevents overloads of the components. Figure III.C.3.a illustrates the areas of the lower block that have a single load path. Two load attaching points of at least the specified capacity are provided when the applicant's rigging is not compatible with an oversized single attaching point. Figure III.C.3.a also illustrates the type of dual load attaching point lower block used when facility constraints dictate that one be used.
C.3.b	The applicant is responsible for the lifting devices attached to the load block.
C.3.c	When higher speed hoisting is required for non-critical loads, key operated cutout switches are provided to restrict the hoisting speed, while handling critical loads, to that specified in this regulatory position.
C.3.d	The Balanced Dual Redundant Reeving System meets this regulatory position.
C.3.e	Figure III.C.3.e illustrates the two types of Balanced Dual Reeving Systems used with X-SAM hoists. The special safety features of HIPS preclude damage to the crane cables from two blocking, load hangup, or overloads. Thus, the most severe condition imposed on the cable occurs when the shared load is transferred to the intact reeving, following failure of a cable in the other reeving. Appendices E and I describe the analysis of cable loading following such a

Regulatory Position	**Additional Information**

failure. Therefore, the wire rope is selected such that the lead lines are capable of safely withstanding the peak static and dynamic loads imposed by this incident, without exceeding 90% of the yield strength of the wire rope. The wire rope manufacturer's published yield strength is multiplied by the wire rope's published "reserve strength" to provide a more conservative margin for wear and fatigue than is provided in the Balanced Dual Reeving Systems supplied with non-X-SAM Cranes. These criteria can be restated in terms of the following equation for calculating the minimum required wire rope breaking strength:

$$S = \frac{(.5)(L + B)(f)(d)}{(.9y)(r)}$$

Where:

S = Minimum required wire rope breaking strength in pounds.

L = Design rated load in pounds.

B =Lower block weight in pounds.

f = Lead line factor of one side of reeving.

$$y = \frac{\text{Published Yield Strength of Wire Rope}}{\text{Published Breaking Strength of Wire Rope}}$$

r = Published 'Reserve Strength' of Wire Rope

d =Dynamic factor from Appendix E or I =about 3 (worst case).

The margin of safety implied in these criteria appears in the '.9' term, which limits the tension to 90% of the yield strength of the wire rope, and in the 'r' term, which assumes that none of the outer wires of the rope are present. It should be noted that ANSI B30.2.0 requires the wire rope to be replaced when the wear of the outer wire exceeds one-third the original diameter of the outside individual wires. This amount of wear represents a loss of only 10% to 16% of the total metallic area of typical 6 x 36 Class IWRC wire rope. Replacing the wire rope, when required by ANSI B30.2.0, also ensures that degradation of the wire rope by fatigue will be limited to approximately 6%. By using the reserve strength to account for wear and fatigue, the above equation assumes that the wire rope metallic area has been reduced by 35% to 55%.

The above criterion is used instead of the one in the regulatory position, which appears to assume that the crane will not be able to safely absorb the high speed kinetic energy in the event of a two blocking.

Regulatory Position	Additional Information
	The maximum line speed of the wire rope is kept below 50 fpm for hoists with capacities greater than 30 Tons. The maximum line speed for compact hoists and auxiliary hoists is consistent with CMAA No. 70's suggested slow operating speed.
C.3.f	The fleet angle restrictions of this regulatory position are met in order that the wire rope will not be cut or crushed in the event a two blocking occurs.
C.3.g	The portions of the vertical hoisting system components, which include the head block, rope reeving system, load block, and load-attaching device are designed to support a minimum static load of 200% the load imposed on them by the maximum critical load. The sample Critical Items List (Appendix A) identifies the nondestructive examinations and load tests to be performed on load attaching points.
C.3.h	The EATL and the wire rope absorb the kinetic energy of the rotating machinery in the event of a control system malfunction. The Hydraulic load Equalization System actuates the Failure Detection System, which de-energizes the motor and sets the high speed holding brake in the event of a wire rope failure. The primary motion of the lower block, following a single wire rope failure, is the vertical displacement associated with the transfer of the shared load to the intact reeving. The alternate design Hydraulic Equalizer System may allow the load to lower until the equalizer contacts the trolley structure. Appendices E and I describe the analysis of the maximum load motion and the kinetic energy associated with it. In any case, the results of the calculation of the maximum kinetic energy and the total vertical displacement of the load are provided to the applicant for use in verifying that the facility design will accommodate this limited controlled load motion.
C.3.i	The actual control system design is specified by the applicant. Interlocks to prevent trolley and bridge movements while fuel elements are being lifted, when recommended by Regulatory Guide 1.13.

Regulatory Position	Additional Information
C.3.j	The EATL provides the ability to absorb the kinetic energy of two blocking or load hangup. The alternative protective features allowed by this position are also incorporated. Appendix F contains an analysis of the lead line and machinery loading following two blocking of a crane protected by an EATL. The analysis described in Section 6.A of Appendix F is used to verify that the lead line loading, if a high speed two blocking occurs while making a critical lift, will not exceed Westinghouse's wire rope criteria described in Paragraph C.3.e above. The results described in Section 5 of Appendix F indicate that even if the EATL does not actuate during such a high speed two blocking, there is still a substantial margin of safety in the cables, since they are not cut or crushed by the two blocking. In some applications a non-single-failure-proof hoist, either main or auxiliary, is provided in conjunction with an X-SAM Hoist. In such cases the non-single failure proof hoist will have at least two independent travel limit switches to minimize the likelihood of an empty block two blocking over a critical area.
C.3.k	The Drum Safety Supports are provided to meet this regulatory position. See Section D.4 for further information on the Drum Safety Supports.
C.3.l	The EATL protects the individual components of the hoisting system from application of excessive drive motor torque.
C.3.m	Only the Emergency Drum Brake System is operable following a drive train failure. However, alone, this system has more emergency lowering capability than two conventional high speed holding brakes have together. Indication of drum lowering speed, which does not require power to the crane, is provided. The Emergency Drum Brake System is capable of continuously lowering the rated load from the maximum hook height without exceeding the temperature limits of the brakes.
C.3.n	The conventional redundant holding brake system located on the high speed shafting is fail safe since the failure of any component between the holding brakes and the hoisting drum would be detected by the Failure Detection System, which would then set the Emergency Drum Brake.
C.3.o	The control system design includes features to prevent abrupt change in motion if jogging or plugging is allowed. The drift point for bridge and trolley movement is at the low end of the controller movement.

Regulatory Position	Additional Information
C.3.p C.3.q C.3.r	The provisions of these regulatory positions are met by X-SAM Cranes and retrofit equipment supplied by Westinghouse in accordance with Generic Licensing Topical Report. Separate overspeed sensors, which actuate the trolley and bridge drive brakes, are not provided when AC motors that inherently cannot overspeed, are used, i.e., when their maximum speed is limited by the 60 HZ line frequency.
C.3.s	Westinghouse establishes X-SAM Cranes' Maximum Critical Load Rating equal to the Design Rated Load. An extra margin for wire rope wear and fatigue is provided in Westinghouse's design criteria for the wire rope, which is described in Section C.3.e above.Westinghouse's X-SAM Crane design also provides margin in the form of additional substantive safety features. These features protect the crane from the unidentified overloadings and operator abuse, which are responsible for much of the expected degradation of cranes during operation.
C.3.t	The applicant is responsible for inspection and certifications of permanent plant cranes, used for construction, prior to handling critical loads.
C.3.u	Westinghouse Field Service Personnel oversee the erection and installation of X-SAM Cranes. Operating instructions provided to the applicant include information on the special safety systems, as well as operating and maintenance instructions for the conventional equipment.
C.4.a	Westinghouse Field Service Personnel, in conjunction with the applicant, make a complete mechanical check of all crane systems to verify proper installation. Required information concerning proof testing of crane components and subsystems performed by or for Westinghouse are included in the Quality Records Package that is shipped with the crane.
C.4.b	The specified testing can be performed by the applicant on X-SAM Cranes, including the demonstration of the manual lowering capability afforded by the Emergency Drum Brake. X-SAM Cranes can also be two blocked during the hoisting test to provide assurance of the integrity of the design, equipment, controls, and overload protection devices. Section G of this report describes Westinghouse's recommended two blocking/overload tests.
C.4.c	If the applicant performs the preventive maintenance specified by Westinghouse, including replacement of the wire rope when required by ANSI B30.2, the Maximum Critical Load Rating can be maintained equal to the Design Rated Load. The substantive safety features of X-SAM Cranes provide the desired margin of safety needed to account for degradation of wear susceptible component parts.
C.4.d	A cold proof test of X-SAM Cranes is not required, since the required material testing of Regulatory Positions C.1.b(2) is provided. The applicant is responsible for inspection, testing and certification of existing crane structures when X-SAM's safety features are backfitted into existing facilities.

Regulatory Position	Additional Information
C.5.a	The applicant is responsible for the quality assurance program for site assembly, installation, and testing of the crane. Westinghouse's Quality Assurance Manual implements the pertinent provisions of Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50 for design and manufacture of X-SAM Cranes. Westinghouse's X-SAM Cranes incorporate components produced at various locations by one or more divisions of Westinghouse and by various suppliers to Westinghouse. From time to time during the manufacturing process it may be necessary, in order to meet demand for particular types of cranes and equipment, or to meet federally mandated safety standards, or Nuclear Regulatory Commission requirements, or for other reasons, to produce Westinghouse products with different components or differently sourced components than the typical components described or illustrated in this Report. All components are approved for use in Westinghouse's X-SAM Cranes by the Westinghouse Engineering and Quality Assurance Departments, and provide equivalent quality and performance described by this Generic Licensing Topical Report. Subcontractors are normally involved in the following operations on Westinghouse fabricated equipment: fabrication, rolling, welding, and nondestructive examination of welded drum shells and oversized structural components; forging and machining of large gear blanks and hooks; painting of major components; and fabrication of some electrical control packages. Most nondestructive examination at Westinghouse is performed by an independent test lab. Consultants provide Westinghouse specialized technical support in seismic analysis, licensing, and quality assurance. When required, consultants also supplement Westinghouse's engineering capability in design and detailing of cranes.
C.5.b	Project Quality Assurance Plans for X-SAM Cranes invoke the Westinghouse Quality Assurance Manual. The Project Quality Assurance Plans address the recommendations of Regulatory Guide 1.104 in the Critical Items List. The Critical Items List for a specific crane is based upon Appendix A. Adjustments to the list are made to accommodate the detailed design and the actual components provided. The nondestructive examinations, quality documentation, and special inspections provided are equivalent to those indicated by Appendix A. Only those items and services identified on the Critical Items List are subject to the controls of Westinghouse's Quality Assurance Manual. Other equipment is provided in accordance with the manufacturers' customary procedures and design practices.

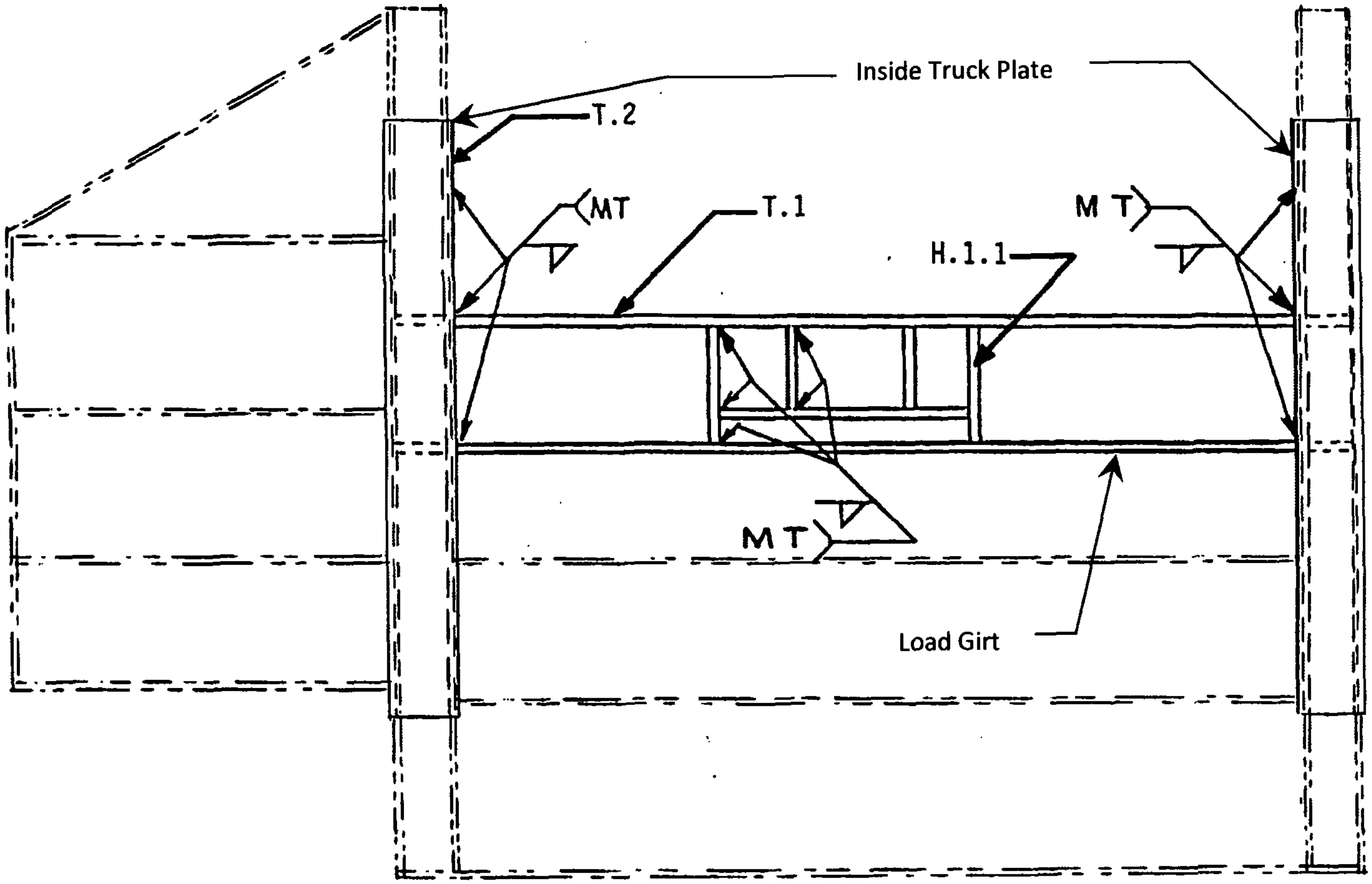
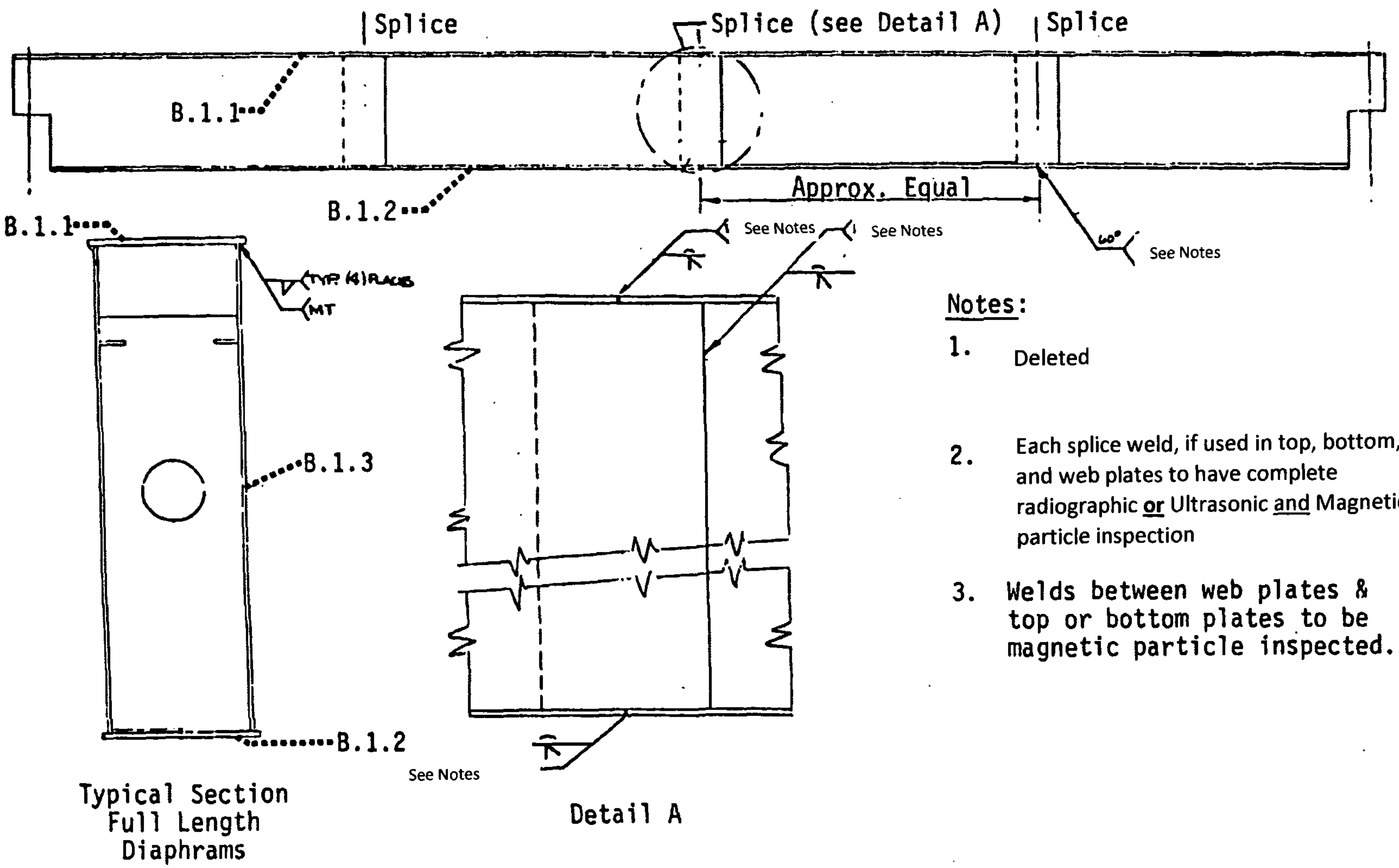


Figure III.C.1.d.1
Typical Trolley Structural Welds



Notes:

1. Deleted

2. Each splice weld, if used in top, bottom, and web plates to have complete radiographic <u>or</u> Ultrasonic <u>and</u> Magnetic particle inspection

3. Welds between web plates & top or bottom plates to be magnetic particle inspected.

Figure III.C.1.d.2
Typical Girder Structural Welds

b

Figure III.C.3.a
Typical Load Attaching Points

b

Figure III.C.3.e
Typical Balanced Reeving Diagram

H. Key Safety System Component Descriptions

4. Emergency Drum Brake

Figure III.D.I depicts two typical pneumatically released, spring set Emergency Drum Brakes. Insome instances, tandem brakes may be utilized to provide the required braking. The reference design is also compatible with hydraulically released, spring set Emergency Drum Brakes. Both disk and band brakes are compatible methods of engaging the drum. Brakes, which have been proven in other industrial applications, some of which involve extended energy dissipation, are selected.

The pneumatically released Emergency Drum Brakes are designed such that their friction surfaces remain in contact even when the brake is not engaged. The brake's retarding torque is directly proportional to the force applied to the actuator, which in turn is directly proportional to the distance the actuator moves. Motion of the actuator would normally be expected to follow an exponential decay as the pressure, which holds the brake open, is bled off. However, for simplicity in analysis, Westinghouse assumes that the brake engagement is linear with time once it has been actuated by the Failure Detection System and that the time to complete actuation is the same as for the real brake. Therefore, at any given time during the engagement period, the actual brake, with the same timing characteristics as those assumed in the analysis, will provide more braking. Thus, the analysis is conservative. Section G.3 describes the testing performed to establish the time required for the brake to fully engage following actuation by the Failure Detection System, as well as the fully engaged retarding torque developed by the, Emergency Drum Brake.

When necessitated by space restrictions or other facility-dependent design parameters for large capacity cranes, the Emergency Drum Brake may be located on a higher speed shaft of an independent increasing speed gear train. In these cases, the added rotational inertia of the system is considered and accommodated during two blocking. The brakes are sized so that their thermal capacity will still be sufficient to continuously lower the maximum critical load from the maximum work height. When this arrangement is used, the Drive Train Continuity Detector will detect continuity from the drum brake shaft to the motor shaft in order to assure that a failure in the gear train to the brake would be detected.

Appendix H describes a continuously engaged Emergency Drum Brake.

5. Energy Absorbing Torque Limiter

Figure III.D.2 depicts two typical EATL designs and the location of the EATL within the gear case. The number of friction surfaces is varied to suit the torque requirements. The torque at which these typical EATLs actuate is adjusted using the adjustment nut(s).

6. Drive Train Continuity Detectors

Figure III.D.3 is a generic block diagram of a Drive Train Continuity Detector. It detects a loss of drive train continuity by monitoring the hoist drum shaft speed and the differential

rotation between the high speed motor and the hoist drum shafts. Depending upon the location of the discontinuity, it is indicated by either a drum overspeed condition or by excess differential rotation between the two shafts. In monitoring the differential rotation of the high speed motor and hoist drum shafts, the Drive Train Continuity Detector automatically accounts for the gear ratio between the two shafts.

The functions of the Drive Train Continuity Detector can be performed either in a digital or analog manner. As described below, the components shown in Figure III.D.3 can be electronic, electrical, mechanical, or a combination of these types of equipment. Regardless of the type of components used, the Drive Train Continuity Detector is designed such that any single failure in it will either actuate the Failure Detection System or will not prevent detection of a drive train discontinuity.

Figure III.D.3.a is a schematic diagram of a typical electronic Drive Train Continuity Detector. It is made up of industrial grade electrical and electronics equipment. Digital transducers driven by the hoist drum and high speed motor shafts provide the information input to the comparison circuits. The comparison circuits are comprised of a number of catalog integrated circuits. Analog electronic components can be used in a similar manner. In either case, the single failure criteria of Reference G are invoked on the design of the electronic Drive Train Continuity Detectors. Reference H is the basis used for qualifying and testing electronic Drive Train Continuity Detectors. Since a failure of both the drive train and the Drive Train Continuity Detector would be required for a loss of the load, the redundancy provisions of References G and H are not applicable.

Figure III.D.3.b is a schematic diagram of a typical mechanical Drive Train Continuity Detector that functions in an analogous manner to the electronic detector shown in Figure III.D.3.b. This detector mechanically compares the differential rotation of the high speed motor and the hoist drum shafts and actuates the Failure Detection System when the prescribed amount of differential rotation is exceeded. A torque limiter coupling protects the differential motion detector from excessive inertial forces that might result from a drum gear failure. Sufficient drag is introduced on either side of the differential to allow detection of a detector shaft or torque limiter failure.

To avoid spurious trips caused by gear backlash, the differential indicator does not actuate the Failure Detection System until a preset amount of differential rotation of the two shafts has occurred. The differential indicator is periodically reset to avoid spurious trips caused by the accumulation of system noise or minute slippage of the EATL over a large number of operating cycles. The reset periods are selected to assure that any undetectable, uncontrolled load motion is within the plant specified limits. Some or all of the components in this arrangement can be replaced with electrical servos and counters.

The type of detectors shown in Figures III.D.3.a and III.D.3.b directly detect sexcess differential rotation between the high speed motor and hoist drum shafts. Figure III.D.3.c illustrates a mechanical continuity detector that performs the same function by monitoring the rate of differential rotation between the two shafts. With this type of design, a separate reset function is not required to avoid spurious trip. Also with this approach it is not

necessary to exactly match the total reduction of the detector to the drive train's reduction. The minimum detectable differential velocity is selected to assure that any undetectable, uncontrolled load motion is within the plant specified limits. During normal operation of this type detector, the high speed motor drives the worm through the differential. The drag on the differential is set at a level that drives the worm at the rate allowed by the rate the drum rotates the worm wheel. The rate of rotation of the differential is determined by the difference in the total reduction of the detector and the drive train. With this design alternative, a drive train discontinuity is detected by:

h. The drum overspeed detector, as in the other alternatives, if the drive train failure occurs near the hoist drum

i. A longitudinal force exerted by the worm wheel on the worm when the drum attempts to drive the worm wheel faster than the rate of rotation of the worm will allow

j. An excessive rate of differential rotation resulting from EATL slippage during a two blocking

In this design, sufficient drag is introduced on the differential and the worm wheel to allow detection of a shaft failure. A torque limiter is provided in the shaft to the worm wheel to protect the detector from excessive torques once the discontinuity has been detected.

The types of Drive Train Continuity Detectors shown in Figures III.D.3.a, b, and c actuate solenoids that vent the pneumatic pressure that holds the Emergency Drum Brake pads away from the braking surface. A mechanical Drive Train Continuity Detector that is capable of developing sufficient force to restrain a mechanical Drum Brake Actuator developed initially for use in X-SAM Cranes provided to the space program and hot metal industry. This capability was an essential element in the development of a Compact X-SAM Hoist. Appendix G describes the operation of both this type of Drive Train Continuity Detector and the Drum Brake Actuator that it operates.

Appendix H describes the type of Drive Train Continuity Detector used for the continuously engaged Emergency Drum Brake. The continuously engaged Emergency Drum Brake is another method for making X-SAM practical for Compact Hoists.

7. Drum Safety Structure

Figure III.D.4 depicts a typical Drum Safety Structure, which serves to limit the motion of the drum following failure of the drum shaft, drum hub, or bearings. This structure, located on both ends of the drum, keeps the drum gear and Emergency Drum Brake from disengaging sufficiently to prevent them from supporting the load. Figure III.D.4 also shows an alternate design Drum Support Structure built into the trolley structure that is compatible with the reference design when there is no net upward force exerted by the drum pinion. With this alternate design, which is provided at both ends of the drum, the drum drops a small distance onto the safety support, where it is safely cradled.

8. Hydraulic Load Equalization System

Figure III.D.5 contains schematic diagrams of typical Hydraulic Equalization Systems. The pressure relief and or flow control valves will protect the hydraulic system and the intact reeving from excessive stress. In the original hydraulic schematic design, the relief setting is at a pressure corresponding to 150% of the equilibrium tension in the intact wire rope. The hydraulic equalization arrangements will be designed to resist the maximum ripe load from a broken rope, which is conservatively 3 times design single line pull. An independent hydraulic fluid flow control is used to retard the motion of the ends of the reeving in the event of a single wire rope failure. This hydraulic fluid flow control is provided by a flow control valve, or a velocity fuse and or orifice device.

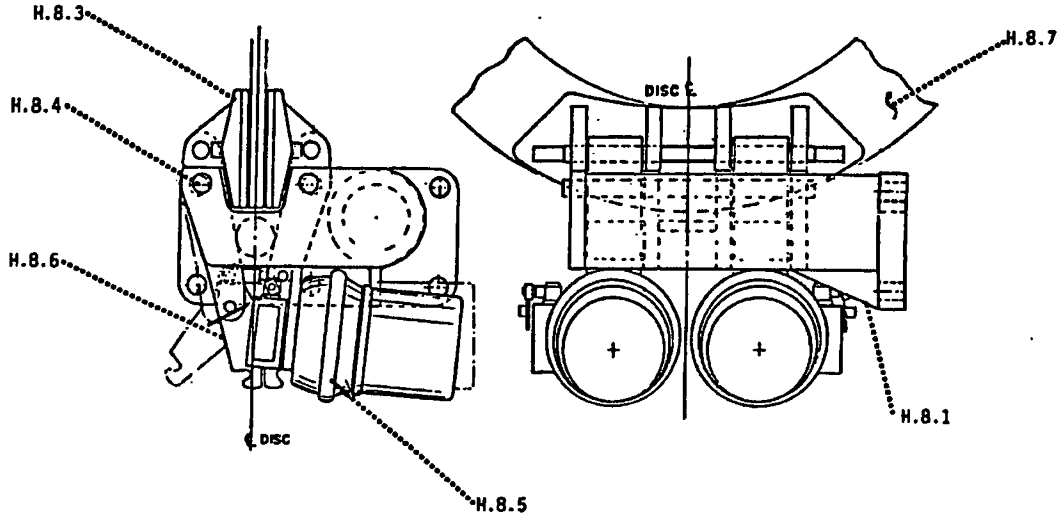
Alternatively, Figure III.D.5 also illustrates a more compact Hydraulic Equalization System that was developed initially for the Compact X-SAM Hoist. This system includes a shock absorber that limits the impact forces applied to the equalizer and crane structure as the equalizer rotates into contact with the structure following a wire rope failure. In the process a small additional amount of load motion occurs, as is calculated in accordance with Appendix I.

9. Lower Block and Hook

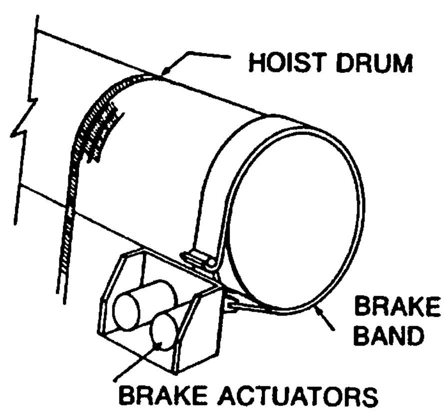
Figure III.C.3.a and III.D.6 depict typical lower blocks and hooks. The number of sheaves is adjusted to suit the hoist capacity.

10. Wire Rope Spooling Monitor

Figure III.A identifies the location of the wire rope spooling monitor. The wire rope spooling monitor consists of a rod positioned across the entire grooved area of the drum so that it is tripped by the wire rope if the wire rope crosses a groove in the drum or if the wire rope wraps over itself. During normal spooling the cylinder does not contact the wire rope or any moving parts of the drum. The electrical proximity switches are actuated by the motion of the rod that results from improper wire rope spooling.



DISC BRAKE



BAND BRAKE

Figure III.D.1
Typical Emergency Drum Brake Designs

b

Figure III.D.2
Typical Energy Absorbing Torque Limiter Designs

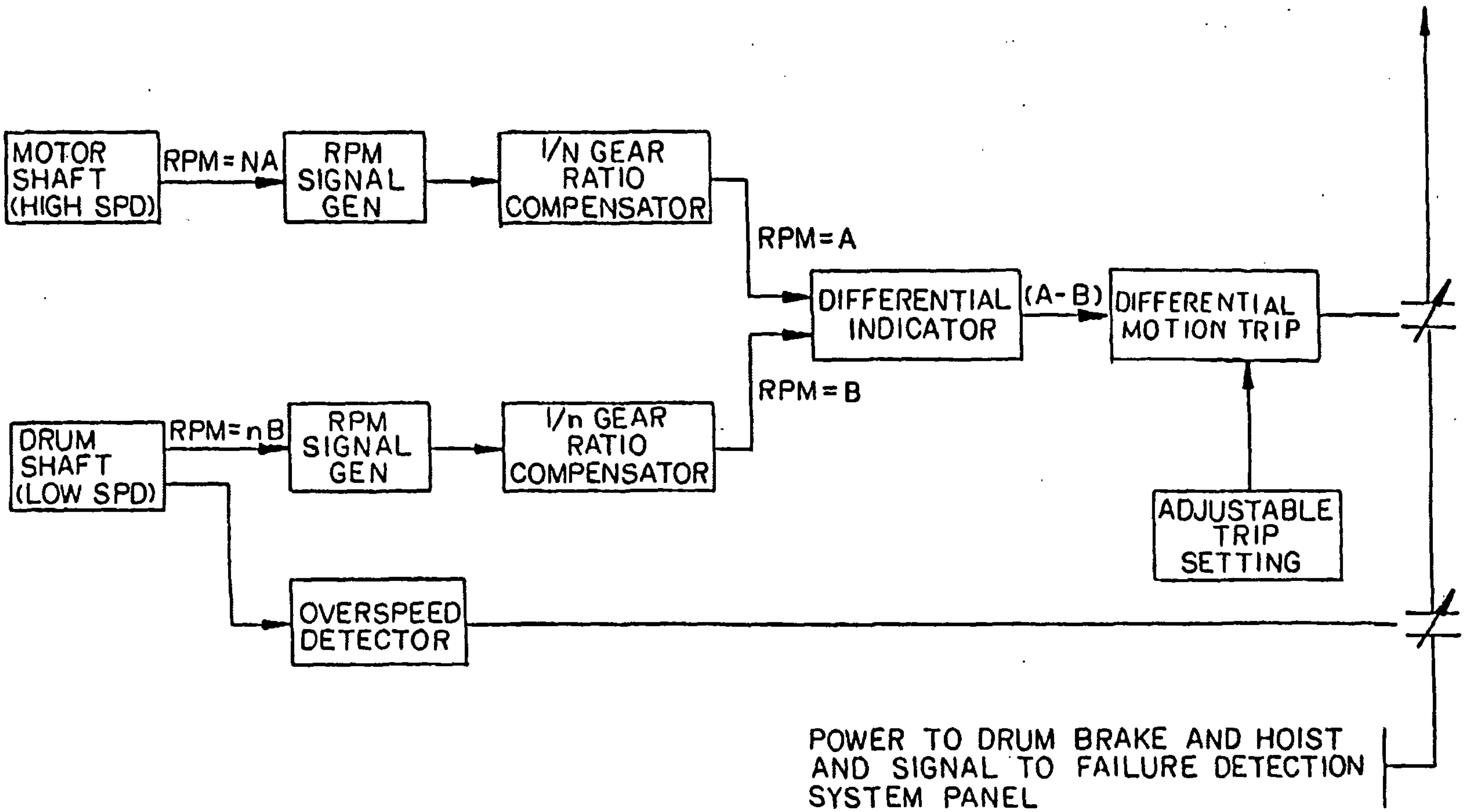


Figure III.D.3
Generic Drive Train Continuity Detector

b

Figure III.D.3.a
Typical Electronic Drive Train Continuity Detector

b

Figure III.D.3.b
Typical Mechanical Drive Train Continuity Detector

b

Figure III.D.3.c
Typical Alternate Concept Mechanical Drive Train Continuity Detector

b

Figure III.D.4
Typical Drum Safety Support Structure

b

Figure III.D.5
Typical Hydraulic Equalization Arrangements

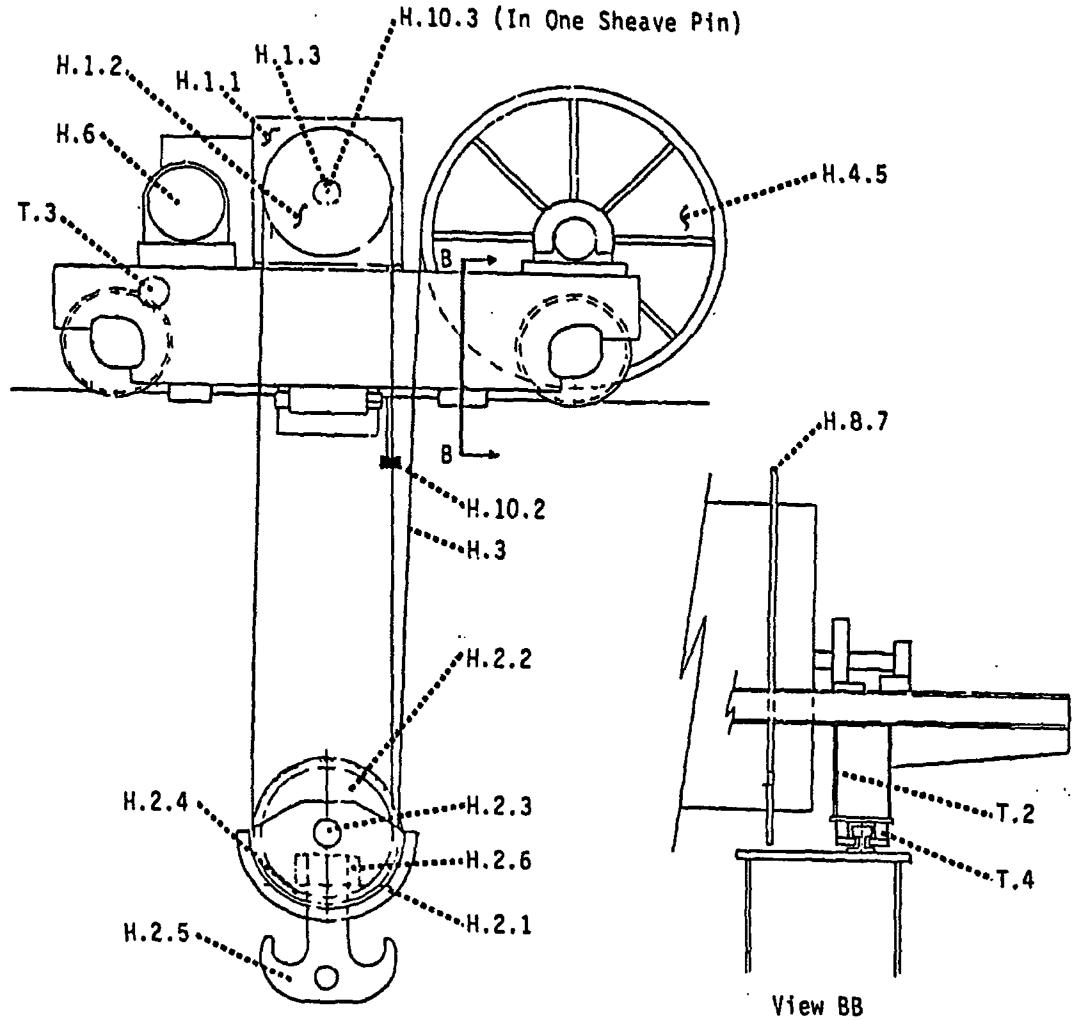


Figure III.D.6
Depiction of Typical Critical Items (See Appendix A for Explanation of Items)

I. Single-Failure-Analysis of Hoist

Defense in depth is provided by the Hoist's Integrated Protective System (HIPS) of Westinghouse's X-SAM Cranes. These systems are designed to allow the X-SAM cranes to safely withstand incidents and operator errors that would cause catastrophic failures in most conventional cranes. However, to assure that operators do not routinely rely on the safety features of the HIPS, the Failure Detection System cannot be reset following serious incidents without access to a locked panel or the key to a key operated switch. This feature allows management the prerogative, through control of the key to the panel or switch, to prevent continued operation of the crane following a serious failure or operator abuse.

If the crane is properly serviced and operated, the Failure Detection System will never be actuated during normal crane operations. The following paragraphs describe the performance of X-SAM Cranes during a variety of serious incidents.

10. Overload – On overload, the X-SAM Cranes' standard electronic load sensing and automatic cutout system interrupts power to the hoist motor and sets the holding brakes. Shutdown by the electronic load sensor does not actuate the Failure Detection System of the HIPS.

    Minor overloads, which the operator attempts to pick up gradually, will not actuate the Energy Absorbing Torque Limiter (EATL) or the Failure Detection System of the HIPS. Thus, the crane can be restarted without access to the locked panel under these conditions.

    If the operator attempts to "snatch" a large or immovable load, or if the electronic system fails to perform its function during an overload, the EATL will limit the load imposed upon the crane. When the EATL limits the load it actuates the Failure Detection System, which means that access to the locked panel will be required to restart the crane following this type of incident.

11. Load Hangup – In the event of a hangup of the load, the kinetic energy of the high speed rotating machinery will be absorbed by the EATL, protecting the hoist machinery, reeving, and crane structure. However, unless the EATL torque setting has been reduced to be consistent with the weight of the load, the crane's design hoisting force may be imposed on the load and its rigging, during an instantaneous, rigid load hangup.

    Some protection of the load and its rigging is afforded by the adjustment option that is available in addition to the standard electronic load sensing system. With this option, the load sensing system can be set for any pre-determined hoisting force, providing it is less than the design rated load of the hoist. If the load exceeds this setting, power to the hoist motor is interrupted and the high speed holding brakes are set. Depending upon how quickly the load hangup occurs, the high speed holding brakes may have time to engage and absorb part of the high speed kinetic energy before the design rated hoisting force can be imposed on the load or its rigging. The electronic load sensing system does not actuate the Failure Detection System, and the Emergency Drum Brake System is not set. Therefore, the crane can be restarted by changing the setting if only the electronic load sensing system actuates.

12. Two Blocking – Two blockings during operations are normally prevented by a primary upper rotary travel limit switch on the hoist drum and a backup upper limit switch on the upper block. Actuation of either limit switch de-energizes the hoisting motor, which sets the high speed holding brakes. The crane can be reactivated by reversing the hoist control and backing out of the first limit switch. Actuation of the backup limit switch also actuates the Failure Detection System, since it will not actuate unless there has been a primary limit switch or control system failure. The Failure Detection System sets the Emergency Drum Brake, which removes all power to the hoist. Of course, failure of both limit switches to actuate, or their inability to de-energize the motor, results in a mechanical two blocking.

    Mechanical two blocking a hoist protected by HIPS simply causes the EATL to actuate, which is detected by the Failure Detection System, setting the Emergency Drum Brake System. The load is retained in a safe condition, even if an electrical short circuit prevents removal of power from the hoist motor, since the EATL is capable of dissipating the entire energy input to the motor while still transmitting sufficient torque to hold the load.

    Even if the EATL fails to actuate at the specified torque setting during a two blocking or load hangup, Appendix F indicates that, the wire rope has substantial ability to continue to hold the load if it is not cut or crushed.

13. Hoist Drive Train Failure – When a significant discontinuity between the motor shaft and the wire rope drum, e.g., failure of a key, shaft, coupling or gear, or actuation of the EATL, is detected, the Failure Detection System sets the Emergency Drum Brake System-interrupting the power to the hoist motor. Appendix E describes the analysis that Westinghouse uses to determine the amount of load motion that can result from a drive train component failure. The maximum calculated load motion and load kinetic energy is provided to the applicant for use in verifying that the facility design can safely accommodate this amount of controlled load motion. When required, the Emergency Drum Brake can be automatically engaged prior to traversing with the load. In this condition, no load motion will follow a single drive train failure while the load is traversing over critical areas.

14. Drum Support Failure – Following a drum support failure, the drum will be safely held by the Drum Safety Structure. The failure would be sensed when the EATL slipped and/or a discontinuity is created in the drive train. The Failure Detection System would also be actuated, setting the Emergency Drum Brake System when the EATL actuates. The Emergency Drum Brake System is still capable of holding the drum when it is supported by the Drum Safety Structure.

15. Overspeed – Overspeed can occur only if there has been a major mechanical or control system failure. Overspeed following a control system failure is sensed by the motor overspeed detector. A control system failure may prevent the high speed holding brakes from engaging. Therefore, drum overspeed actuates the Failure Detection System, which sets the Emergency Drum Brake System.

The drum overspeed detector is part of the Drive Train Continuity Detectors, so it also actuates the Failure Detection System if a mechanical failure results in an overspeed condition.

16. Total Loss of Power While Hoisting a Critical Load – A total loss of electrical power sets the conventional high speed holding brake and, if the load starts to lower, the Emergency Drum Brake as well, thereby stopping the load.

    Substantial capability for lowering a load to a safe resting place, following a total loss of electrical power, is provided by HIPS. Its Emergency Drum Brake System provides a large margin of safety under these conditions because of the brake's substantial thermal capacity. The rated load can be safely lowered continuously from maximum hook height to the floor without exceeding the temperature limits of the brakes. It is not necessary to stop the load frequently, as is required when only conventional holding brakes are used.

17. Hoist Control System Failure – HIPS protects against the consequences of a hoist control system failure, which results either in an overspeed condition or inability to remove hoisting power. The EATL is capable of dissipating the full energy output of the drive motor until the Emergency Drum Brake System sets, if the motor cannot be de-energized and a two blocking results. The Emergency Drum Brake also provides the operator an independent means of manually stopping a load in the event a control system failure prevents the conventional holding brake from setting while the control system's regenerative braking is operating. Thus, the Emergency Drum Brake restores most of the protection provided by mechanical load brakes, which was lost when electrical load controls were adopted to obtain improved speed control.

18. Off Center Lifts – In the event an excessive off center lift is made, the Wire Rope Spooling Monitor senses the improper spooling of the wire rope before damage can occur. Because of the potentially catastrophic consequences of damage to the wire rope, the monitor actuates the Failure Detection System, requiring management concurrence to restart the crane.

19. Failure of High Speed Motor Holding Brake – The Emergency Drum Brake System provides a backup to the conventional holding brake during normal operations, since it automatically actuates either on overspeed or as soon as the load starts to lower. With the Emergency Stop Button, the operator is able to manually engage the Emergency Drum Brake System.

20. Cable Failure – The entire load is transferred to the remaining rope system under controlled acceleration and forces. The relationship between the load and the supporting structure is not changed, so load sway is kept to an acceptable level. The failure is automatically detected by the Failure Detection System, which sets the high speed holding brake and actuates the Emergency Drum Brake System. Depending upon the type of Emergency Drum Brake Actuator that is used, the Emergency Drum Brake may also be set by the Failure Detection System. In any event the Emergency Drum Brake will automatically set if necessary to stop the load from lowering. In this manner the load is retained in a safe, stable

position. In all cases the management concurrence is required to restart the crane since the Failure Detection System was actuated.

The actual amount of vertical displacement of the load depends upon the length of cable unspooled and the weight of the load. Appendices E and I describe the analysis that Westinghouse uses to determine the maximum amount of transient load motion and kinetic energy that can result from a cable failure. A small additional amount of load motion may result when the alternate Hydraulic Equalization System allows the equalizer beam to move into contact with the trolley structure. This additional load motion is calculated, as described in Appendix I, and is provided to the applicant for use in verifying that the facility design can safely accommodate this amount of controlled load motion.

J. Envelope of Design Characteristics and the Design Criteria Utilized to Extend the Reference Design to Complete Cranes for New Facilities

21. Typical Design Characteristics – The reference design utilizes the same basic approaches to meeting the requirements of Regulatory Guide 1.104, independent of the capacity of the hoist. Table III.F.I summarizes the design characteristics of reference design X-SAM hoists with capacities typical of four different applications in nuclear power plants. For particular facility applications some of the characteristics listed in Figure III.F.I are adjusted to suit the specific capacity and specified configuration of the trolley, e.g., with or without auxiliary hoist and the facility space envelope. Appendix B identifies the design characteristics Westinghouse provides for licensing of specific X-SAM Hoists.

22. Complete Cranes for New Facilities – The reference design hoisting system is equally applicable to complete cranes for new facilities. The detailed girder design is developed and analyzed in accordance with Reference F, Regulatory Guide 1.104, and the site-specific seismic requirements.

Table III.F.I
Typical Characteristics of Four Different Capacity X-SAM Hoists of the Reference Designs

Application	Compact Hoist	Medium Capacity Main Hoist	Fuel Cask Handling Crane	Containment Building Polar Crane
Crane Classification	A-1(1)	A-1(1)	A-1(1)	A-1(1)
Design Rated Load	10 Tons(2)	50 Tons(2)	130 Tons(2)	250 Tons(2)
Maximum Critical Load Rating	10 Tons	50 Tons	130 Tons	250 Tons
Trolley				
Trolley Runway Rail Size	(I-Beam)	80 lbs.	171 lbs.	171 lbs.
Trolley Weight (net)	5000 lbs.	50,000 lbs.(3)	114,000 lbs.(3)	200,000 lbs.(3)
Trolley Weight (w/load)	25,000 lbs.	150,000 lbs.(3)	374,000 lbs.(3)	550,000 lbs.(3)
No. Wheels – Size	8-6"	4-15"	4-24"	8-24"
Design Speed	30 fpm	30 fpm	30 fpm	30 fpm
Drive Motor	½ hp	½ hp	5 hp	10 hp
Hoist				
Hook Type	Single(4)	Single(4)	Single(4)	Dual(4)
Hook Lift	60 feet(5)	61 feet(5)	77 feet(5)	120 feet(5)
Number of Drums	1	1	1	1 or 2
Drum Size (Pitch Parameter)	18"	38"	70"	70" or 50"
Full Load Hook Speed Max.	15 fpm(6)	4 fpm	4.5 fpm	4 fpm
No Full Load Hook Speed Max.	15 fpm	4 fpm	4.5 fpm	4 fpm
Drive Motor	7.5 hp (A.C.) (7)	15 hp (A.C.) (7)	60 hp (A.C.) (7)	90 hp (A.C.) (7)

Table III.F.I
Typical Characteristics of Four Different Capacity X-SAM Hoists of the Reference Designs (cont.)

Application	Compact Hoist	Medium Capacity Main Hoist	Fuel Cask Handling Crane	Containment Building Polar Crane
Hoist (cont.)				
Controller	Variable Frequency Flux Vector(7)	Variable Frequency Flux Vector(7)	Variable Frequency Flux Vector(7)	Variable Frequency Flux Vector(7)
Control Braking	Dynamic Lowering(7)	Dynamic Lowering(7)	Dynamic Lowering(7)	Dynamic Lowering(7)
Hook Design Load	10 Tons	50 Tons	130 Tons	250 Tons
Hook Load Test	20 Tons	100 Tons	260 Tons	500 Tons
Hoist Reeving System				
Rope Class	6 x 36 IWRC	6 x 36 IWRC	6 x 36 IWRC	6 x 36 IWRC
No. Parts Rope	2 x 4	2 x 4	2 x 8	2 x 8 or 4 x 4
Rope Diameter	½"	1 1/8"	1 ¼"	1 3/8"
Max. Rope Speed	60 fpm	16 fpm	36 fpm	16 fpm – 32 fpm
Exterior Fleet Angle	3.5 degrees	3.5 degrees	3.5 degrees	3.5 degrees
No. Reverse Bends	1	1	1	1
Hoist Safety Features				
No. Ropes	2	2	2	2 or 4
Hook Safety Factor (Minimum)	10(4)	10(4)	10(4)	10(4)
No. Load Cell Devices	1	1	1	1

Table III.F.I
Typical Characteristics of Four Different Capacity X-SAM Hoists of the Reference Designs (cont.)

Application	Compact Hoist	Medium Capacity Main Hoist	Fuel Cask Handling Crane	Containment Building Polar Crane
Hoist Safety Features (cont.)				
Load Equalizer Type	Hydraulic	Hydraulic	Hydraulic	Hydraulic
Holding Brake Type	Spring Set	Spring Set	Spring Set	Spring Set
No. Holding Brakes	1	1	1	1
Holding Brake Capacity	150%	150%	150%	150%
No. Upper Travel Limit Switches	2	2	2	2
No. Lower Travel Limit Switches	1	1	1	1
Energy Absorbing Torque Limiter	1	1	1	1
Failure Detection System	1	1	1	1

Table III.F.I
Typical Characteristics of Four Different Capacity X-SAM Hoists of the Reference Designs (cont.)

Application	Compact Hoist	Medium Capacity Main Hoist	Fuel Cask Handling Crane	Containment Building Polar Crane
Emergency Drum Brake	1	1 tandem brake	1 tandem brake	1 or 2 tandem drum brakes or brake on separate gear train off the drum
Emergency Drum Brake Capacity, total	130%	130%	130%	130%

Notes:

1. Minimum per CMAA 70, actual classification established by applicant's determination of duty cycle.
2. Greater if used for construction or non-critical lifts in excess of required Maximum Critical Load Rating.
3. Approximate dead weight of trolley. Actual weight depends upon whether an auxiliary hoist selected and number of drums selected.
4. Dual load path hook utilized with minimum 5 to 1 factor of safety on each attaching point when facility constraints do not permit use of single load path hook design.
5. Hook lift is established by applicant's facility design requirements.
6. Key operated switch reduces hoisting speed by less than 5 fpm for critical lifts.
7. The reference design represents state-of-the-art controls commonly used for cranes. Selection of the specific type of Controller and Control Braking to be specified by the applicant.

K. Safety System Test Provisions

Standard pre-operational and periodic checks, tests, and maintenance as specified by ANSI B.30.2, OSHA, and Regulatory Guide 1.104 are performed. These tests include the following:

11. Test of Conventional Hoist Safety Systems

k. Tests of Upper Limit Switches – During pre-operational testing, the upper limit switches are tested as follows: The backup limit switch is disconnected and the block is raised at full speed to verify that the primary limit switch functions correctly. Then the primary limit switch is disconnected, the backup limit switch is reconnected and the test is repeated to verify proper operation of the backup limit switch.

   During periodic inspections of the crane as required by OSHA and ANSI B30.2, the upper limit switches are tested as follows: The block is raised at low speed until the primary limit switch is actuated to verify proper operation of the limit switch. Then the primary limit switch is disconnected and the backup limit switch is tested in the same manner.

l. Test of Lower Limit Switch – During pre-operational testing, the lower limit switch is tested as follows: The block is lowered at full speed until the lower limit switch is actuated, thereby verifying proper operation. During periodic testing, this test is conducted at low speed.

m. Test of Overload Sensing System – During pre-operational and periodic inspection testing, the overload sensing system is tested as follows: The upper limit switches are disconnected and the block is very slowly raised until it is touching the bottom of the load girt. At this point, the high speed holding brakes are set and the crane power is shut off. Then a torque wrench is used to bring the cable tension up to the level at which the overload sensing system is set to trip. Power to the hoist motor is restored and if the overload sensing system is operating correctly, it will actuate. If the electronic overload sensing system does not actuate, it is adjusted and the test is repeated until proper operation is verified.

12. Testing of Balanced Dual Reeving System

n. Load Testing in Accordance With OSHA Requirements – Periodic load tests are performed as required by OSHA, ANSI B30.2, and Regulatory Guide 1.104.

o. Test of Hydraulic Load Equalization System – The Hydraulic Load Equalization System is tested and sealed by the manufacturer.

   During pre-operational testing and periodic inspections of the crane, the hydraulic fluid level is checked by the operator by monitoring the oil pressure gauge.

13. Testing of HIPS

p. Test of EATL – During pre-operational and periodic testing, the EATL is checked as follows. The upper limit switches are bypassed and the block is slowly brought into contact with the load girt. The drum brake is set, the holding brakes are released and a torque wrench is used to manually actuate the EATL to verify that it is properly set and operates correctly.

   During pre-operational testing, a slow speed two-blocking test is performed to verify that the EATL protects the hoist during such an incident. During the slow speed two blocking test the upper limit switches are bypassed and the crane is two blocked. The slow speed two blocking test represents the worst case slow speed load hangup. Therefore, a separate load hangup test is not required for X-SAM Cranes.

q. Test of Emergency Drum Brake System – The time required for the Emergency Drum Brake to engage, foll6wing action by the Failure Detection System, is measured with an oscillograph. The fully engaged Emergency Drum Brake dynamic torque is measured by adjusting the EATL to a known torque value at the desired minimum value of Emergency Drum Brake dynamic torque. The hoist is then started and then the Emergency Drum Brake actuated without removing power to the motor. If the actual dynamic brake torque is greater than the minimum the drive train torque will increase to the EATL set point after which EATL actuation will occur.

   During pre-operational and periodic testing, the Emergency Drum Brake is tested when the low speed two blocking test is performed. If the safety systems are operating properly, the brake will set when the EATL actuates.

   During pre-operational testing, the manual lowering capability of the Emergency Drum Brake System is verified by manually lowering the maximum load as required by Regulatory Guide 1.104. The ability of the Emergency Drum Brake to retain the load without the high speed shaft holding brakes is also verified.

   During pre-operational and periodic testing, the drum brake is manually actuated to verify that all power to the crane is interrupted when it engages.

r. Tests of Failure Detection System – Qualification testing and burning in of electronic Failure Detection Systems is accomplished in accordance with the applicable sections of Reference H.

   During pre-operational and periodic testing, operation of the portion of the Drive Train Continuity Detector that monitors the relative rotation of the high speed motor and drum shafts is verified in conjunction with the low speed two blocking test.

During pre-operational and periodic testing, the drum overspeed portion of the Drive Train Continuity Detector is tested by uncoupling the detector shaft and manually rotating it to verify that the detector actuates the Failure Detection System.

The Wire Rope Spooling Monitor is tested during pre-operational and periodic testing by manually actuating it to verify that it actuates the Failure Detection System.

APPENDIX A
SAMPLE CRITICAL ITEMS LIST FOR WESTINGHOUSE'S X-SAM CRANES

List of Abbreviations

H	=	Hoist
B	=	Bridge
T	=	Trolley
O	=	Other
C	=	Consulting
MTR	=	Material Test Report (Includes CP, HP, and/or PP, as appropriate. For commercial parts, includes PV and DV as appropriate.)
CP	=	Material Chemical Properties
PP	=	Material Physical Properties
HP	=	Material Hardness Properties
PV	=	Part Number Verification
DV	=	Dimensional Verification
NDTT	=	Material Nil Ductility Transition Temperature
UT	=	Ultrasonic Test of Material
MP	=	Magnetic Particle Inspection of Material
LP	=	Dye Penetrant Inspection of Material
VW	=	Visual Weld Inspection
MT	=	Magnetic Particle Inspection of Critical Welds
PT	=	Dye Penetrant Inspection of Critical Welds
UW	=	Ultrasonic Inspection of Critical Welds
RT	=	Radiographic Inspection of Critical Welds
N/A	=	Not Applicable
I (M)	=	Mechanical Inspection for Conformance to Detail Drawings
I (S)	=	Structural Inspection for Conformance to Detail Drawings
CC	=	Certificate of Conformance or Certified Data Sheet
SPF	=	Sample Pulled to Failure
LT	=	Load Test
SF	=	Shop Functional Test
PWHT	=	Post-weld Heat treatment
RMTR	=	Routine Motor Test Reports
NDE	=	Non-destructive Examination

Notes

23. Nil Ductility Transition Testing of rolled structural materials shall be performed in accordance with NUREG 0554 Section 2.4. Actual testing of materials for listed item is performed only if material thickness is such that testing is required by the Regulatory Guide.

24. MT or PT inspect the welds, in the listed structure, whose failure could result in loss of the load per AWS D1.1. Acceptance Criteria: AWS D 1.1, 2010.

25. Deleted.

26. Post weld heat treatment per AWS Dl.I, 2010, is normally provided for welded gear cases. Depending upon the detailed design parameters, i.e., material thickness and weld sizes, additional post weld heat treatment of other weldments is also provided.

27. UT inspect material after rough machining per ASTM A-388, 2011. The acceptance standard, using straight beam, is as follows: One or more reflectors which produce complete loss of back reflection, not attributable to geometric configuration, are unacceptable. Complete loss of back reflection is assumed when back reflection falls below 5 percent of full calibration.

28. MP inspect per ASTM E-709, 2008. Acceptance Standard: Cracks, forging laps, or linear indications open to the surface are not allowed. For forged hooks MP inspect per ASTM A 275, 2008. Acceptance Criteria: Same as above plus linear subsurface indications more than ½" long are unacceptable (DC current required).

29. UT inspect hooks per ASTM A-388, 2011 or EN 10228-3, 1998. Acceptance Standard for UT of hooks using straight beam, is as follows: One or more reflectors which produce complete loss of back reflection, not attributable to geometric configuration, are unacceptable. Complete loss of back reflection is assumed when back reflection falls below 5 percent of full calibration.

    A. For custom fabricated hooks, perform the UT examination of billet prior to flame cutting.

    B. After forging and before machining, hooks shall be ultrasonic tested using flat-bottomed hole reference standards and distance-amplitude correction curves. Discontinuity indications in excess of the response from a 1/8" (3mm per EN 10228-3) flat bottomed hole at the estimated discontinuity depth shall be unacceptable.

    C. Because standard catalogue hooks must be inspected in a semi-finished condition, only about 90% of their surfaces are suitable for UT examination.

30. Following load test.

31. RT or UT & MT or PT inspect all full penetration butt welds present, if any, in listed item. Acceptance Criteria: AWS D 1.1,2010.

32. UT inspect:

    D. The area within five inches of both longitudinal edges for the entire length of the plates.
    E. The area within 12 inches of both transverse edges for the entire width of the plates.

33. Deleted.

34. MT or PT inspect the lateral welds between the flange and web plates on the girders. Acceptance Criteria: AWS D 1.1, 2010.

35. UT inspect the plates per ASTM A-578, 2012. Acceptance Standard: Level B.

36. Minimum BHN 321 in tread area.

37. LP inspect per ASTM E-165, 2012 Acceptance Standard: No cracks at points of high stress or at stress risers, with ASTM E-433, 2008 as a reference.

Sample Critical Items List For Westinghouse's X-SAM Cranes

Critical Item Number	Figure Number	Description	Material Test Reports	Non Destructive Examinations	Other/Additional Inspections, Tests, and Certifications
Trolley					
T.1	III.C.1.d.1	Load Girts	MTR NDTT (1)	MT (2)	
T.2	III.C.1.d.1 III.D.6	Truck Structure (Inside Plates)	MTR NDTT (1)	N/A	
T.3	III.D.6	Motors	N/A	N/A	RMTR
T.4	III.D.6	Seismic Restraints	MTR	MT (2)	
T.5	III.D.4	Drum Safety Support	MTR NDTT (1)	MT (2)	
T.6	Not Shown	Drum Brake Mounting Base	MTR NDTT (1)	MT (2)	
T.7	Not Shown	Trolley Overspeed Detector	N/A	N/A	CC SF
T.8	III.D.6	Wheels	MTR HP (14)	N/A	N/A
Hoist with HIPS					
H.1	III.D.6	Upper Block Assembly	–	–	–
H.1.1	III.C.1.d.1 III.D.6	Structure that supports both segments of the redundant reeving system (Side Plates)	MTR NDTT (1)	MT (2)	
H.1.2	III.D.6	Sheaves	MTR MP (6)	N/A	N/A
H.1.3	III.D.6	Sheave Pins	MTR UT (5)	N/A	

Sample Critical Items List For Westinghouse's X-SAM Cranes (cont.)

Critical Item Number	Figure Number	Description	Material Test Reports	Non Destructive Examinations	Other/Additional Inspections, Tests, and Certifications
Hoist with HIPS (cont.)					
H.1.4	III.C.3.e	Equalizer Arm and Support structure	MTR NDTT (1) UT (13)	N/A	
H.1.5	III.C.3.e III.D.5	Hydraulic Load Equalization System	N/A	N/A	CC SF
H.1.5.1	III.C.3.e III.D.5	Hydraulic Load Equalization System Supports	MTR NDTT (1)	MT (2)	
H.2	III.C.3.a III.D.6	Lower Block Assembly	–	–	–
H.2.1	III.C.3.a III.D.6	Structure (Side Plates)	MTR NDTT (1)	MT (2)	
H.2.2	III.C.3.a III.D.6	Sheaves	MTR MP (6)	N/A	N/A
H.2.3	III.C.3.a III.D.6	Sheave Pins	MTR UT (5)	N/A	
H.2.4	III.C.3.a III.D.6	Trunnion	MTR UT (5) MP (6)	N/A	
H.2.5	III.C.3.a III.D.6	Hook	MTR UT (7) MP (6) or LP (15)	N/A	LT 200% MP (6, 8) or LP (8,15)
H.2.6	III.C.3.a	Hook Nut	MTR UT (5) MP (6) or LP (15)	N/A	MP (6, 8) or LP (8,15)

Sample Critical Items List For Westinghouse's X-SAM Cranes (cont.)

Critical Item Number	Figure Number	Description	Material Test Reports	Non Destructive Examinations	Other/Additional Inspections, Tests, and Certifications
Hoist with HIPS (cont.)					
H.3	III.C.3.a III.D.6	Wire Rope	N/A	N/A	CC SPF
H.4	III.A	Drum Assembly	–	–	–
H.4.1	III.D.4	Drum Shell	MTR NDTT (1)	RT (9) Or UT(9) & MT(9) (Drum Shell butt welds only)	
H.4.2	III.D.4	Drum Shaft	MTR UT (5) MP (6)	N/A	
H.4.3	III.A	Drum Gear	MTR	N/A	
H.4.4	III.A	Drum Pinion	MTR	N/A	
H.4.5	III.D.4 III.D.6	Drum Hubs	MTR NDTT (1)	MT (2)	
H.5	III.A	Hoist Reduction Gear Assembly	–	–	–
H.5.1	III.D.2	Gear Case Structural Shell	MTR	N/A	PWHT (4)
H.5.2	III.D.2	Hoist Case Gears	MTR	N/A	
H.5.3	III.D.2	Hoist Case Shafts	MTR	N/A	
H.6	III.A III.D.6	Hoist Motor	N/A	N/A	RMTR
H.7	III.A III.D.2	Energy Absorbing Torque-Limiter	–	–	SF
H.7.1	III.D.2	Spring	MTR	N/A	

Sample Critical Items List For Westinghouse's X-SAM Cranes (cont.)

Critical Item Number	Figure Number	Description	Material Test Reports	Non Destructive Examinations	Other/Additional Inspections, Tests, and Certifications
Hoist with HIPS (cont.)					
H.7.2	III.D.2	Pinion With or Without Spine)	MTR	N/A	
H.7.3	III.D.2	Through Shaft	MTR	N/A	
H.7.4	III.D.2	Gear or Splined Ring	MTR	N/A	
H.7.5	III.D.2	Pressure Plate	MTR	N/A	
H.7.6	III.D.2	Separator Plates (When Applicable)	N/A	N/A	CC
H.7.7	III.D.2	Splined Carrier	MTR	N/A	
H.7.8	III.D.2	Friction Discs	N/A	N/A	CC
H.7.9	III.D.2	Pressure Hubs (When Applicable)	MTR	N/A	
H.7.10	III.D.2	Screw Studs (When Applicable)	MTR	N/A	
H.8	III.A	Emergency Drum Brake System	–	–	–
H.8.1	III.D.1	Brake Frame	MTR	N/A	
H.8.2	III.A	Emergency Actuation Components (When Applicable)	N/A	N/A	CC SF
H.8.3	III.D.1	Actuator Hardware (When Applicable)	MTR	N/A	
H.8.4	III.D.1	Brake Band (When Applicable)	MTR NDTT (1)	N/A	
H.8.5	III.D.1	Brake Anchors (When Applicable)	MTR NDTT (1)	N/A	
H.8.6	III.D.1	Brake Linings (When Applicable)	N/A	N/A	CC

Sample Critical Items List For Westinghouse's X-SAM Cranes (cont.)

Critical Item Number	Figure Number	Description	Material Test Reports	Non Destructive Examinations	Other/Additional Inspections, Tests, and Certifications
Hoist with HIPS (cont.)					
H.8.7	III.D.1 III.D.6	Drum Brake Disc (When Applicable)	MTR NDTT (1)	MT (2)	
H.9	III.A	Failure Detection System	–	–	–
H.9.1	III.D.3	Drive Train Continuity Detector Components	MTR	N/A	CC SF
H.9.2	III.D.3	Drum Overspeed Detector (When Applicable)	N/A	N/A	CC SF
H.9.3	III.A	Wire Rope Spooling Monitor	N/A	N/A	CC SF
H.9.4	–	Failure Actuation & Monitoring Assembly (When Applicable)	N/A	N/A	SF CC
H.10	–	Miscellaneous Hoist Assemblies	–	–	–
H.10.1	III.A	Rotary Limit Switch	N/A	N/A	CC SF
H.10.2	III.D.6	Backup Upper Limit Switch	N/A	N/A	CC SF
H.10.3	III.D.6	Load Sensing System and Overload Protection	N/A	N/A	CC SF

Sample Critical Items List For Westinghouse's X-SAM Cranes (cont.)

Critical Item Number	Figure Number	Description	Material Test Reports	Non Destructive Examinations	Other/Additional Inspections, Tests, and Certifications
Other					
O.1	Not Shown	Weld Material	MTR NDTT as required by AWS	N/A	CC
O.2	Not Shown	Threaded Fasteners for structural interconnections	MTR	N/A	CC
Consulting					
C.1	N/A	Seismic Analyses	N/A	N/A	
C.2	N/A	Drafting and Detailing Services	N/A	N/A	
C.3	N/A	NDE Services	N/A	N/A	
C.4	N/A	Accident Analyses	N/A	N/A	
Bridge (Complete Cranes Only)					
B.1	III.C.1.d.2	Girder Structure	–	–	–
B.1.1	III.C.1.d.2	Top Plate	MTR NDTT (1) UT (13, 10)	RT (9) Or UT (9) & MT (9)	
B.1.2	III.C.1.d.2	Bottom Plate	MTR NDTT (1) UT (13, 10)	RT (9) Or UT (9) & MT (9)	
B.1.3	III.C.1.d.2	Web Plates	MTR NDTT (1) UT (13, 10)	RT (9) & MT (12) Or UT (9) & MT (12)	
B.2	III.A	Motors	N/A	N/A	RMTR
B.3	Similar to T.4	Seismic Restraints	MTR	MT (2)	
B.4	–	Wheels	MTR HP (14)	N/A	N/A

Sample Critical Items List For Westinghouse's X-SAM Cranes (cont.)

Critical Item Number	Figure Number	Description	Material Test Reports	Non Destructive Examinations	Other/Additional Inspections, Tests, and Certifications
Bridge (Complete Cranes Only) (cont.)					
B.5	–	Rails	MTR	N/A	N/A
B.6	–	Axles	MTR	N/A	N/A
B.7	Not Shown	Bridge Overspeed Detector	N/A	N/A	CC SF

APPENDIX B
SUMMARY OF PLANT SPECIFIC CRANE DATA SUPPLIED BY DESIGNER

Regulatory Position	Topical Report Section	Information to be Provided	Specific Crane Data
C.1.a	(C.1.a)	1. The actual crane duty classification of the crane specified by the applicant.	1.
C.1.b	(C.1.b)	1. The minimum operating temperature of the crane specified by the applicant.	1.
C.2.b	(C.2.b) (E.4)	2. The maximum extent of load motion and the peak kinetic energy of the load following a drive train failure. 3. Provisions for actuating the Emergency Drum Brake prior to traversing with the load, when required to accommodate the load motion following a drive train failure.	1. 2.
C.3.e	(C.3.e)	4. The maximum cable loading following a wire rope failure in terms of the acceptance criteria established in Section C.3.e.	1.
C.3.f	–	5. Maximum fleet angle 6. Number of reverse bends 7. Sheave diameter	1. 2. 3.
C.3.h	(C.3.h) (E.II)	8. The maximum extent of motion and peak kinetic energy of the load following a single wire rope failure.	1.
C.3.i	(C.3.i)	9. The type of load control system specified by the applicant. 10. Whether interlocks are recommended by Regulatory Guide 1.13 to prevent trolley and bridge movements while fuel elements are being lifted and whether they are provided for this application.	1. 2.

Regulatory Position	Topical Report Section	Information to be Provided	Specific Crane Data
C.3.j	(C.3.j)	11. The maximum cable and machinery loading that would result in the event of a high speed two blocking, assuming a control system malfunction that would allow the full breakdown torque of the motor to be applied to the drive motor shaft. 12. Means of preventing two blocking of auxiliary hoists, if provided.	1. 2.
C.3.k	(C.3.k)	13. Type of drum safety support provided.	1.
C.3.o	–	14. Type of hoist drive to provide incremental motion.	1.
C.3.p	–	15. Maximum trolley speed. 16. Maximum bridge speed. 17. Type of overspeed protection for the trolley and bridge drives.	1. 2. 3.
C.3.q	–	18. Control station location.	1.
–	(D.1)	19. The type of Emergency Drum Brake used, including type of release mechanism. 20. The relative location of the Emergency Drum Brake. 21. Emergency Drum Brake Capacity.	1. 2. 3.
–	(D.2)	22. Number of friction surfaces in EATL. 23. EATL Torque setting.	1. 2.
–	(D.3)	24. Type of Failure Detection System.	1.
–	(D.5)	25. Type of Hydraulic Load Equalization System	1.
–	(D.6)	26. Type of hook. 27. Hook design load. 28. Hook load test.	1. 2. 3.

Regulatory Position	Topical Report Section	Information to be Provided	Specific Crane Data
–	(F.1)	29. Design rated load.	1.
		30. Maximum critical load rating.	2.
		31. Trolley weight (net).	3.
		32. Trolley weight (with load).	4.
		33. Hook lift.	5.
		34. Number of wire rope drums.	6.
		35. Number of parts of wire rope.	7.
		36. Drum size (pitch diameter)	8.
		37. Wire rope diameter.	9.
		38. Wire rope type.	10.
		39. Wire rope material.	11.
		40. Wire rope breaking strength.	12.
		41. Wire rope yield strength.	13.
		42. Wire rope reserve strength.	14.
		43. Number of wire ropes.	15.

APPENDIX C
SUMMARY OF REGULATORY POSITIONS TO BE ADDRESSED BY THE APPLICANT

Regulatory Position	Topical Section Report	Information to be Provided	Specific Crane Data
–	(C.1.b (1))	44. The extent of venting of closed box sections.	1.
C.1.b (3) C.1.b (4) C.4.d	(C.1.b (3)) (C.1.b (4)) (C.4.d)	45. The nondestructive and cold proof testing to be performed on existing structural members for which satisfactory impact test data is not available.	1.
C.1.c	(C.1.c)	46. The extent the crane's structures, which are not being replaced, are capable of meeting the seismic requirements of Regulatory Guide 1.29.	1.
C.1.d	(C.1.d)	47. The extent welds joints in the crane's structures, which are not being replaced, were nondestructively examined, and 48. The extent the base material, at joints susceptible to lamellar tearing, was nondestructively examined.	1. 2.
C.1.e	(C.1.e)	49. The extent the crane's structures, which are not being replaced, are capable of withstanding the fatigue effects of cyclic loading from previous and projected usage, including any construction usage.	1.
C.1.f	(C.1.f)	50. The extent the crane's structures, which are not being replaced, were post-weld heat-treated in accordance with AWS D1.1, "Structural Welding Code."	1.

Regulatory Position	Topical Section Report	Information to be Provided	Specific Crane Data
C.2.b	(C.2.b) (E.4)	51. Provisions for accommodating the load motion and kinetic energy following a drive train failure when the load is being traversed and when it is being raised or lowered.	1.
C.2.c	(C.2.c)	52. Location of safe laydown areas for use in the event repairs to the crane are required that cannot be made with the load suspended.	1.
C.2.d	(C.2.d)	53. Size of replacement components that can be brought into the building for repair of the crane without having to break its integrity, 54. Location of area where repair work can be accomplished on the crane without affecting the safe shut-down capability of the reactor, and 55. Any limitations on reactor operations that would result from crane repairs.	1. 2. 3.
C.3.b	(C.3.b)	56. The design margin and type of lifting devices that are attached to the hook to carry critical loads.	1.
C.3.t	(C.3.t)	57. The extent construction requirements for the crane's structures, which will not be replaced, are more severe than those for permanent plant service. 58. The modifications, and inspections to be accomplished on the crane following construction use, which was more severe than those for permanent plant service.	1. 2.

Regulatory Position	Topical Section Report	Information to be Provided	Specific Crane Data
C.3.u	–	59. The extent of installation and operating instructions.	1.
C.4.a C.4.b C.4.c C.4.d		60. The extent of assembly checkout, test procedures, load testing and rated load marking of the crane.	1.
C.5.d	(C.5.a)	61. The extent the procurement documents for the crane's structures, which will not be replaced, required the crane manufacturer to provide a quality assurance program consistent with the pertinent provisions of Regulatory Guide 1.28.	1.

APPENDIX D
SUMMARY OF LESSONS LEARNED IN RETROFITTING THE NEW TROLLEY ON THE LOFT CONTAINMENT BUILDING POLAR CRANE

REVISION 7

Assistance in Preparation Provided by:

HOLLORAN & ASSOCIATES
Mechanical and Nuclear Engineering Services
Suite 102
205 108th Ave NE

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Table of Contents and Revision Status for Appendix D

SUMMARY OF LESSONS LEARNED IN RETROFITTING THE NEW TROLLEY ON THE LOFT CONTAINMENT BUILDING POLAR CRANE

1. Introduction

1.1 The document summarizes the lessons learned from the shop and field testing of the LOFT Trolley. The shop testing sequence, with charts of cable loading during two blocking tests are also included.

2. Shop Tests

2.1 The two blocking tests of the LOFT Crane were conducted in the Ederer shop from April 22 to April 27, 1978. A shop test sequence was used. Several two-blocking tests were conducted on each hoist.

2.2 The conditions unique to the shop testing environment included:

38. The trolley was positioned on blocks in the Ederer Production Shop such that sufficient clearance was available for approximately 4 feet vertical movement of the lower block.

39. DC electrical power to the hoist was provided by a motor generator set. [ ][a,c]

2.3 The test sequence was the same for both the main and auxiliary hoists. Two blocking tests were conducted using several different motor torques and speeds to obtain variations in the wire rope load. [

][a,c]

[

]a,c

2.4 The attached figures represent typical results of the two blocking tests. After comparing many sets of test data, inferences have been drawn as to what phenomenon caused a certain curve shape on the test data. These phenomenon are marked by dotted lines on Figures I through 6. Each individual figure contains the pertinent descriptive information of the test results:

[

]a,c

3 Lessons Learned

3.1 The lessons learned during the shop testing and field installation involved correction of mechanical and electronic malfunctions. These malfunctions did not affect the ability of the hoist to withstand a two-blocking or load hang-up.

3.2 Lessons Learned During Shop Testing

[

]a,c

[

]a,c

[

]^a,c^

3.3 Lessons Learned During Field Installation

[

]^a,c^

[

]a,c

b

Figure 1
Two Blocking of the Main Hoist With Peak Torque Apparently Below the Torque Setting of the EATL

b

Figure 2
Two Blocking of the Main Hoist Where EATL Slipped

b

Figure 3
Two Blocking of the Auxiliary Hoist Where EATL Slipped Without Chatter

b

Figure 4
Two Blocking of the Auxiliary Hoist Where Torque Limiter Slipped Without Chatter

b

Figure 5
Two Blocking of the Auxiliary Hoist With Special Rubber Damping Devices Installed

b

Figure 6
Two Blocking of the Main Hoist

APPENDIX E
ANALYSIS OF LOAD MOTION AND CABLE LOADING FOLLOWING A SINGLE DRIVE TRAIN FAILURE OR WIRE ROPE FAILURE IN AN X-SAM TYPE CRANE

R.W. Holloran

M.N. McDermott

R.E. Morton

C.A. Rusch

REVISION 7

Assistance in Preparation Provided by:

HOLLORAN & ASSOCIATES
Mechanical and Nuclear Engineering Services
Suite 102
205 108th Ave NE

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Table of Contents and Revision Status for Appendix E

Table of Contents and Revision Status for Appendix E (cont.)

1. Introduction

The purpose of this report is to describe the analytical and numerical techniques developed for evaluating the consequences of a drive train failure in a single drive train hoist that is equipped with an emergency drum brake, which is actuated by a drum overspeed detector or drive train continuity detector. These techniques also can be used to evaluate the consequences of failure of a single wire rope in a dual reeved crane that is protected by an energy absorbing torque limiter in the drive train. Section 2 describes the analytical approach to the wire rope failure problem.

Since the complete solution for an actual drive train or wire rope failure cannot be expressed in a simple form, a FORTRAN program solving these problems was developed. Sample numerical results from the program are provided in Section 3 for a reference design hoist, with three different sets of assumptions regarding emergency drum brake performance. Section 4 provides two different sets of numerical results for a wire rope failure in the reference design hoist.

Section 5 explains the mathematical model used. Expressions for the displacement and kinetic energy of the load, as a function of time following the failure, are developed in Sections 6 and 7. These expressions provide a basis for evaluating the consequences of the failures on the equipment and structures under the load. Expressions for the tension in the wire ropes are also developed in Sections 6 and 7 in order to determine whether the ropes would be overloaded by the incidents. Section 8 summarizes the basis for using the tackle system efficiency to account for sheave friction and inertia in the analysis.

2. Approach

The analysis starts with the equations of motion for the following two general cases: (1) the wire rope drum is rotating, and (2) the wire rope drum is being held stationary by a friction brake or energy absorbing torque limiter. See Figure 10 for a diagram of the hoist model used in deriving the equations.

The solutions given for these general cases are valid only if certain physical conditions are met. Specifically, the solution to the case where the drum is rotating is valid only if the time derivative of the braking torque remains constant, and the drum continues to move in the lowering direction. The solution for the stationary drum case is valid only as long as the torque applied on the drum by the tension in the wire ropes is less than the torque required for the emergency drum brake to start slipping. These conditions are not always valid in the situations of interest. The complete solutions for specific cases at all times of interest are obtained by dividing the problem into a series of time regions in which the appropriate physical conditions are properly modeled. The relevant general solution is applied to each of these time regions in turn.

The two solutions of the general cases are sufficiently complicated to make the complete expressions for load displacement, velocity, etc., intractable if the formal expressions for these quantities at the end of each region are used for the initial conditions of the next region. To get around this difficulty, the solutions are evaluated numerically one region at a time. Appropriate

tests are used in the numerical solutions to determine the time when one region ends and another starts. The numerical results calculated for the end of a region provide the initial conditions for the numerical solution in the following region.

Analysis of a drive train failure typically involves the following regions:

s. The interval between the drive train failure and the start of braking. This region is characterized by a constant retarding torque, which is usually assummed to be zero, but not necessarily. The end of this region occurs when the specified braking reaction time has elapsed following occurrence of a drum overspeed trip or detection of a drive train discontinuity.

t. The interval between the start of braking and the full engagement of the drum brake. This region is characterized by a linearly increasing retarding torque, starting from the constant retarding torque present in the first region. This region ends when the drum brake is fully engaged, i.e., the design value of the dynamic retarding torque of the drum brake is reached, or when the drum stops rotating.

u. The interval between the full engagement of the emergency drum brake and the time when the drum stops rotating.

v. The interval between the stopping of the drum and the resumption of emergency drum brake slipping. This region ends when the tension in the wire ropes increases sufficiently to apply a torque on the drum that is greater than the emergency drum brake can hold, at which time the conditions of paragraph c. above, are again appropriate. The solution alternates between these two final regions until sufficient energy has been removed from the system to prevent the tension in the wire rope from exceeding the level at which the drum brake will slip. Once this condition is met, the stationary drum region of this paragraph is appropriate for all subsequent times.

The analysis of a single wire rope failure starts with the drum being held by the static retarding torque of the EATL. This region is very similar to region d. above, with the exception of the initial conditions. This region ends when the tension in the wire rope exceeds that which is required for the EATL to actuate or when the emergency drum brake starts to engage.

The next region will be comparable to a. or b. above, depending upon which condition ended the initial region. The applicable static or dynamic retarding torque of the EATL is used, in addition to the retarding torque automatically applied by the emergency drum brake, during the remainder of the analysis.

3. Summary of the Drive Train Failure Results

The equations of Sections 6 and 7 were programmed in FORTRAN on a CDC 6400/CYBER 73 computer system. Results of three sample drive train failure analyses are presented in the CALCOMP plots that follow. The figures provide plots of the load motion, kinetic energy, and cable tension (not including lead line efficiency) for a base case drive train failure (reference

design with nominal configuration and damping) superimposed on: (1) the base case without damping and (2) a similar case where the times associated with braking are increased by 50 percent. It should be noted that, because the kinetic energy of the load becomes so large during the incident relative to the kinetic energy of the load moving at rated speed, it is difficult to see that the initial energy is nonzero and does, in fact, account for initial load velocity.

Input constants, which were the same for all cases of a particular design, are listed in Table 1. Input parameters that vary are listed in Table 2 for the base case and Table 3 for the case of slower braking. Figures 1 through 3 show the base case superimposed on the same case without damping. Figures 4 through 6 show the base case superimposed on the same case with 50 percent longer braking times.

Table 1
Reference Design Case Independent Constants

Drum Radius	2.88 feet
Drum Moment of Inertia	4106 slug-ft^2
Weight of Load	260000 lb
Rated Load	260000 lb
Number of Parts of Cable	8
Rope Modulus of Elasticity	1.2×10^7 PSI
Rope Metal Area	.79 in^2
Rope Length When Two Blocked	80 feet

Table 2 and Table 3

TABLE 2
REFERENCE DESIGN BASE CASE CONSTANTS

TABLE 3
REFERENCE DESIGN WITH 50% LONGER BRAKING TIMES

a,c

b

Figure 1
Displacement of Base Case and Base Case Without Damping

b

Figure 2
Tension of Base Case and Base Case Without Damping

b

Figure 3
Kinetic Energy of Base Case and Base Case Without Damping

b

Figure 4
Displacement of Base Case and Base Case With 50% Longer Braking Time

b

Figure 5
Tension of Base Case and Base Case With 50% Longer Braking Times

b

Figure 6
Kinetic Energy of Base Case and Base Case With 50% Longer Braking Times

4. Summary of the Single Wire Rope Failure Results

The equations of Section 7 were programmed in FORTRAN on a CDC 6400/ CYBER 73 computer system. If the emergency drum brake is actuated quickly enough, the EATL will not actuate. [

][a,c]

Figures 7, 8, and 9 provide sample CALCOMP plots of the load motion, kinetic energy, and cable tension (not including the tackle system efficiency) following a single wire rope failure of the reference design crane (both with and without the damping assumed in the drive train failure analysis). The appropriate crane design parameters of Table 1, and the variable input data of Table 4, were used to generate these figures.

Table 4
Rope Break Analysis Reference Design Base Case Constants

a,c

b

Figure 7
Displacement of Base Case and Base Case Without Damping

b

Figure 8
Tension of Base Case and Base Case Without Damping

b

Figure 9
Kinetic Energy of Base Case and Base Case Without Damping

5. Description of Mathematical Model

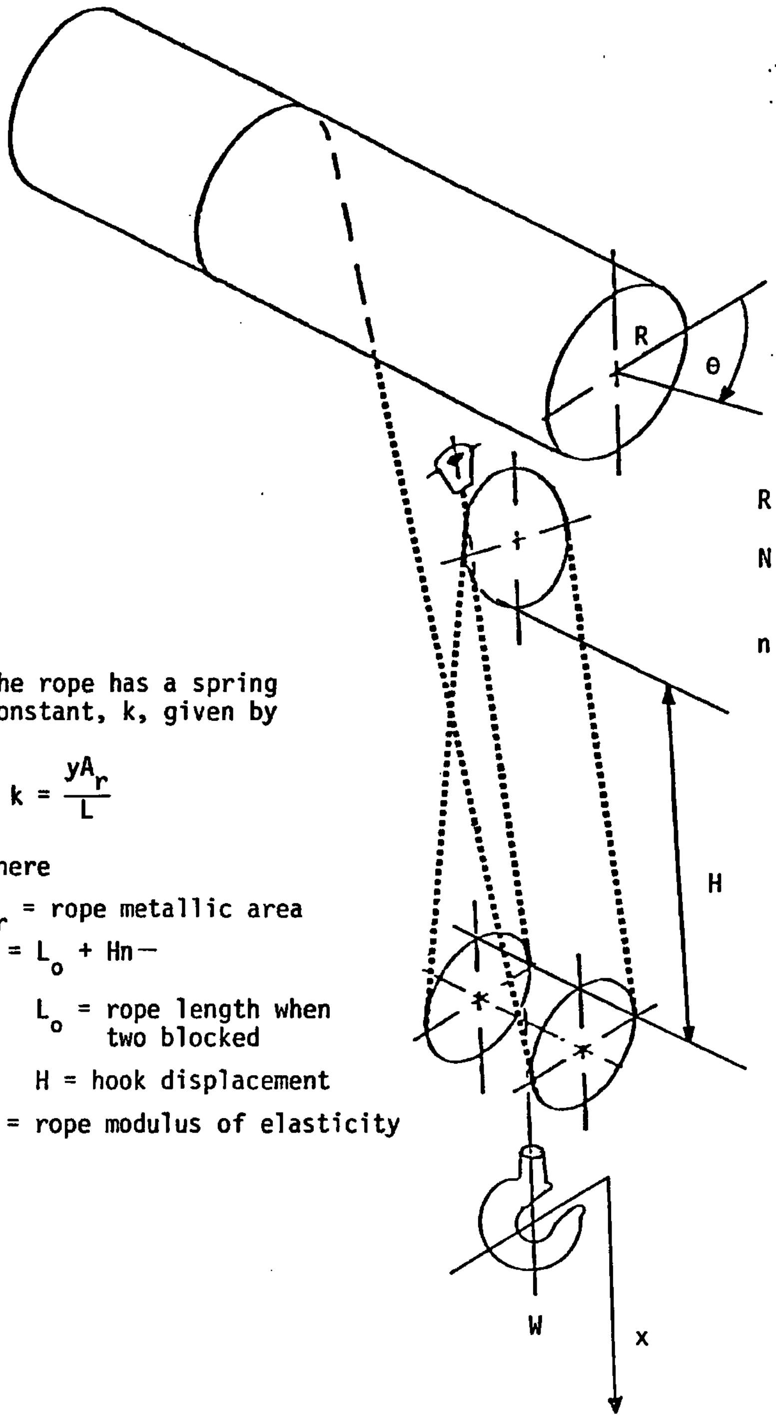
This section describes the mathematical model of the hoist that is used to derive the general solutions and to link them to obtain the specific solutions for individual cases.

a. Model of Crane

Figure 10 shows a typical reeving arrangement, the pertinent physical parameters, and the sign conventions used. The following assumptions are made:

[

]^{a,c}



R = drum radius

N = number of ropes attached to Drum and Equalizer

n = number of parts of line in one rope

The rope has a spring constant, k, given by

$$k = \frac{yA_r}{L}$$

where

A_r = rope metallic area

$L = L_o + Hn$—

L_o = rope length when two blocked

H = hook displacement

y = rope modulus of elasticity

Figure 10
Typical Reeving System

[

]a,c

b. Model of Drive Train Failure Detection System

A drive train failure can be detected either directly, by a drive train continuity detector, or indirectly, by a drum overspeed detector. A drum overspeed detector also detects a holding brake failure, which a drive train continuity detector alone would not detect.

[

]a,c

c. Model of Emergency Drum Brake

[

]a,c

[

]a,c

d. Model of Hydraulic Equalization System

The Hydraulic Load Equalization System is assumed to function such that the bitter end of the two wire ropes remains stationary following a wire rope failure.

e. Model of Failure

The failure is assumed to happen instantaneously. In the case of a drive train failure, the failure is assumed to be a complete severing of the drive train at a given point. After the failure, the drum is restrained only by the moment of inertia of the intact portions of the drive train connected to the drum and whatever constant retarded braking is assumed. Therefore, the drum accelerates in response to the difference between the force applied by the ropes and the restraining forces. In a wire rope break, the failure is assumed to be a complete severing of one wire rope, with the attendant increase in static and dynamic tension in the remaining rope and additional dynamic forces on the drum resulting from the load motion.

6. General Solution of the Equations of Motion that is Valid When the Drum is Rotating

[

]a,c

[

]^{a,c}

[

][a,c]

[

]^{a,c}

7. General Solution of the Equations of Motion That is Valid When the Drum is Stationary

[

]^{a,c}

[

]a,c

[

]a,c

8. Assessment of the Effects of Sheave Inertia and Bearing Friction

[

]a,c

The simplified analysis described above indicates that including sheave effects through use of the tackle system efficiency produces conservative estimates of the maximum tension in the wire rope. Furthermore, the actual load motion will be smaller and slower than that predicted without sheave effects.

APPENDIX F
ANALYSIS OF CABLE AND MACHINERY LOADINGS FOLLOWING TWO BLOCKINGS OF X-SAM TYPE CRANES

R.W. Holloran

C.A. Rusch

R.E. Morton

M.N. McDermott

REVISION 7

Assistance in Preparation Provided by:

HOLLORAN & ASSOCIATES
Mechanical and Nuclear Engineering Services
Suite 102
205 108th Ave NE

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Table of Contents and Revision Status for Appendix F

Table of Contents and Revision Status for Appendix F (cont.)

1. Introduction

The purpose of this analysis is to develop analytical and numerical techniques for evaluating the consequences of a two blocking in a single drive train hoist protected by an energy absorbing torque limiter (EATL). Specifically, expressions for drum hoist displacement and cable tension, as a function of time following the two blocking, are developed. These expressions provide a basis for evaluating the consequences of a two blocking on the cables and machinery.

2. Approach

The analysis starts with the equations of motion following the two blocking of a crane without an EATL. From this basic case, the expressions are extended to include a crane with an EATL. Finally, damping, motor shutdown, and variable spring constants are included in the analysis to provide a model that can closely approximate the results generated from actual two blocking tests.

3. Description of the Mathematical Model

f. Model Description

A crane two blocking creates a situation in which the lower (moving) block stops, by coming in contact with the trolley, while the torque applied by the drive motor increases the cable tension rather than lifting the load. The cable tension will increase until the stall torque of the motor is reached, if an EATL is not installed. [

]a,c

g. Model Assumptions and Definitions

This section describes the mathematical model of the hoist that is used to derive the general solutions for cable and machinery loading. Figure 1 shows a typical reeving arrangement, the pertinent physical parameters, and the sign conventions used. The following assumptions are made:

1. The hoist and trolley structures are rigid;
2. The hoist motor turns at a constant speed unless it reaches its stall torque, at which time a constant torque is applied.
3. The use of an effective moment of inertia, calculated with respect to the hoist drum axis, accounts for the inertia effects of the hoist motor, hoist drum, gears, and gear shafts, and the gear ratio of these pieces relative to the drum. It is given by:

$$I_{eff} = \sum_{shafts}(I_{shaft})\,(Shaft\ Reduction)^2 \qquad (2)$$

$$I_{shaft} = \sum_{components}\frac{\pi\rho L}{2}\left(R_0{}^4 - R_i{}^4\right) \qquad (3)$$

where L = length of the Component (e.g., gear)

R_0 = Outside Radius of Component

R_i = Inside Radius of Component

ρ = Density of the Component Material

40. The load is shared equally between nN parts of line.

41. The hoist cable reacts as an elastic spring.

42. Sheave inertia can be neglected.

43. Use of an effective length corrects for the effects of the sheaves on the spring constant. The effective length is obtained from the expression:

$$L = \sum_{i=1}^{n} \frac{l_i}{k^{i-1}} = \frac{l_1}{k^0} + \frac{l_2}{k^1} + \frac{l_3}{k^2} + \frac{l_4}{k^3} + \ldots + \frac{l_n}{k^{n-1}} \quad (1)$$

where l_i is the length of the rope between the $(i+1)^{th}$ and the $(i)^{th}$ sheave, k is the ratio of tension in the rope unwinding from the sheave to the tension in the rope winding onto the sheave, and n is the number of parts of line in a single rope.

44. The lead line tension while hoisting, $\boldsymbol{P}$, is related to the average tension, $\boldsymbol{T_s}$, by the tackle system efficiency, $\boldsymbol{E}$, as follows:

$$P = \frac{T_s}{E} \quad (4)$$

Table F.2 contains the derivation of the expression for the tackle system efficiency.

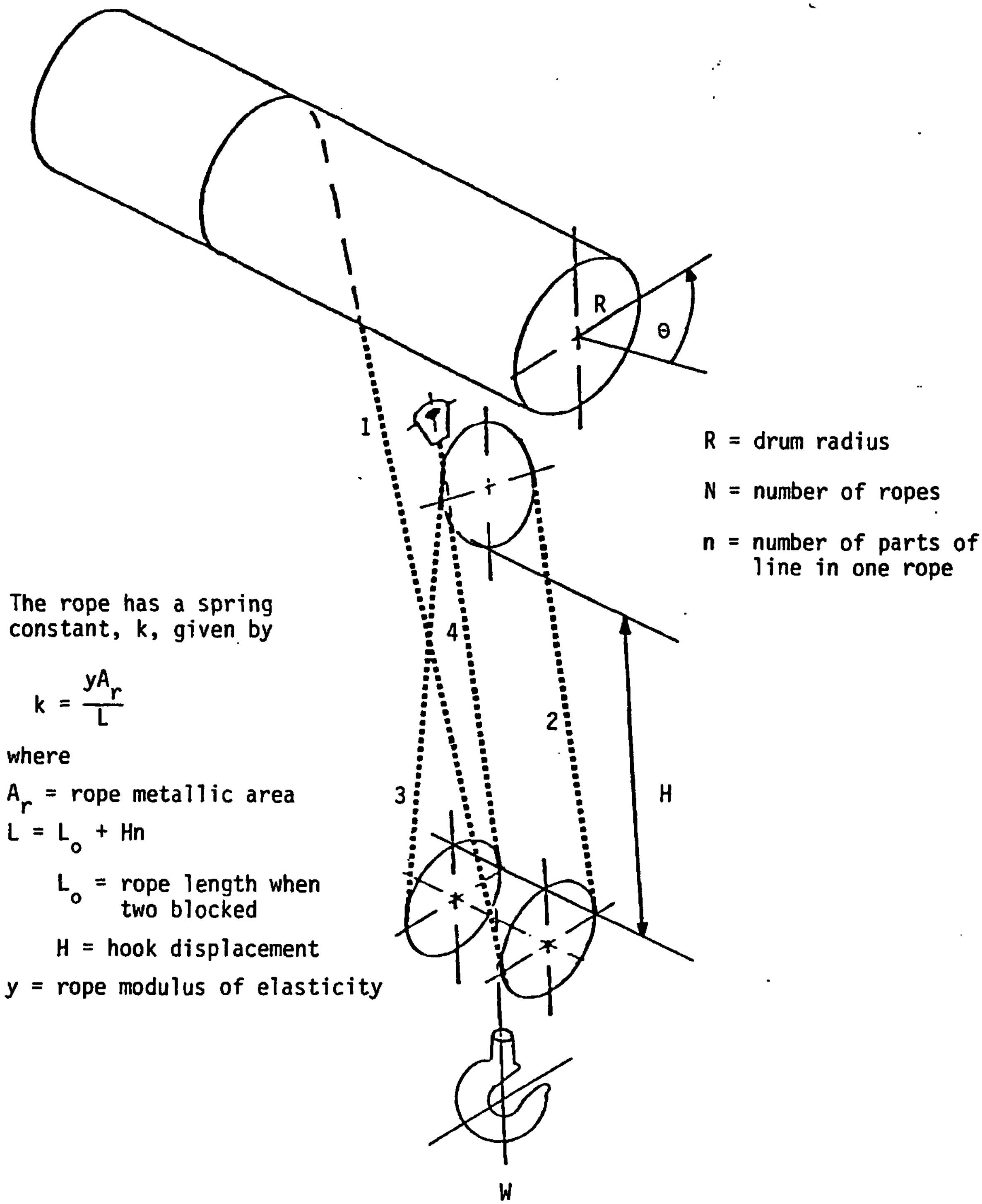

Figure 1
Typical Reeving System

4. Solutions for Cable and Machinery Loading for a Crane Without an EATL Following a Two Blocking

A drum of radius R carrying N ropes, turns to lift the load (Figure 1). An effective moment of inertia I is used for the system, which is calculated with respect to the hoist drum axis of rotation. Figure 2 represents a typical hoist drive system without EATL. The wire rope is assumed to be fully elastic and is characterized by a spring constant k. The spring constant is obtained from the expression:

$$k = \frac{yA_r}{L} \tag{5}$$

where y is the elastic modulus of the wire rope, A_r is the metallic cross sectional area of the rope, and L is the effective length of one of the wire ropes. The effective length accounts for the sheave friction effects on the spring constant. The inertial effects of the sheaves are neglected and the system is assumed to be undamped.

For N identical ropes on the drum and a time varying torque $J(t)$ applied by the motor to the drum, the dynamical equation that gives the angle θ through which the drum rotates following two blocking, with $\theta = 0$ at $t = 0$, is:

$$I = \frac{d^2\theta}{dt^2} = J(t) - kNR^2\theta - NRP \tag{6}$$

where the tackle system efficiency is used in calculating P, the initial tension in one lead line prior to two blocking. The case considered is one in which the angular velocity of the drum remains constant until a limiting torque is reached, whereupon the torque remains constant at its limiting value. This case is closely approximated by crane systems that are designed to hoist at virtually a constant speed, i.e., DC systems. Figure 3 illustrates the assumed torque-speed curve for a typical DC motor. The vertical lines represent the speed regulation of a DC motor controller in which the speed is maintained for any torque below the stall torque. Figure 4 represents two speed points of an AC motor torque-speed curve, in which the speed decreases with increasing torque and fewer resistors remain in the circuit as the Speed Point increases. When Speed Point 5 is selected, all resistors are out of the circuit and the torque speed curve approaches a vertical relationship similar to that of a DC motor. The AC motor can conservatively be assumed to have the speed control torque characteristics of a DC motor. A more accurate solution, which accounts for ramp torque speed relationships, is presented in Table F.3 for use when a less conservative solution is desired. This solution approaches the constant angular velocity solution as resistors are cut out of the AC motor control circuit.

The solution to equation (6) divides naturally into two regions. The first region applies to the time prior to reaching the torque limit.

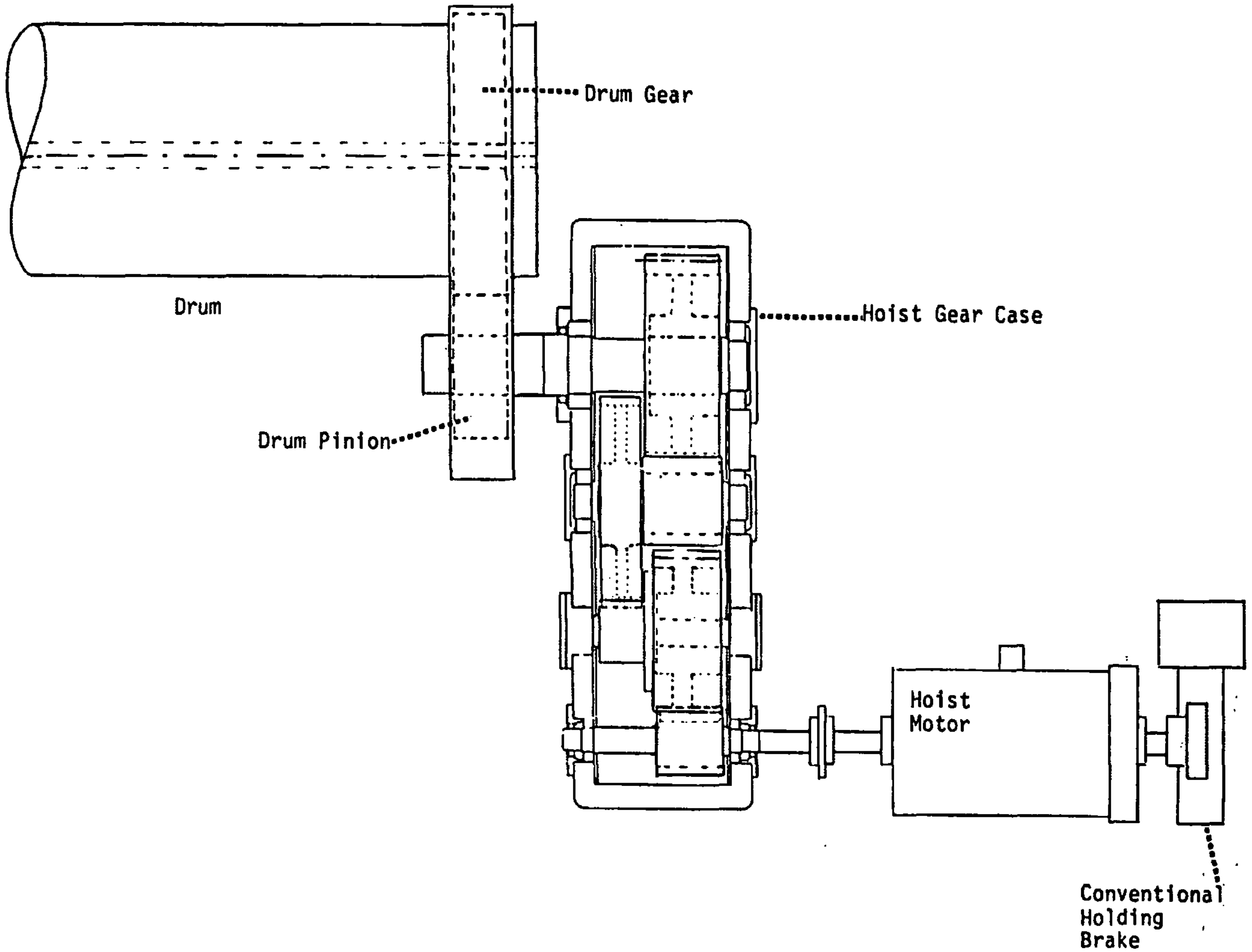

Figure 2
Typical Hoist Drive System Without EATL

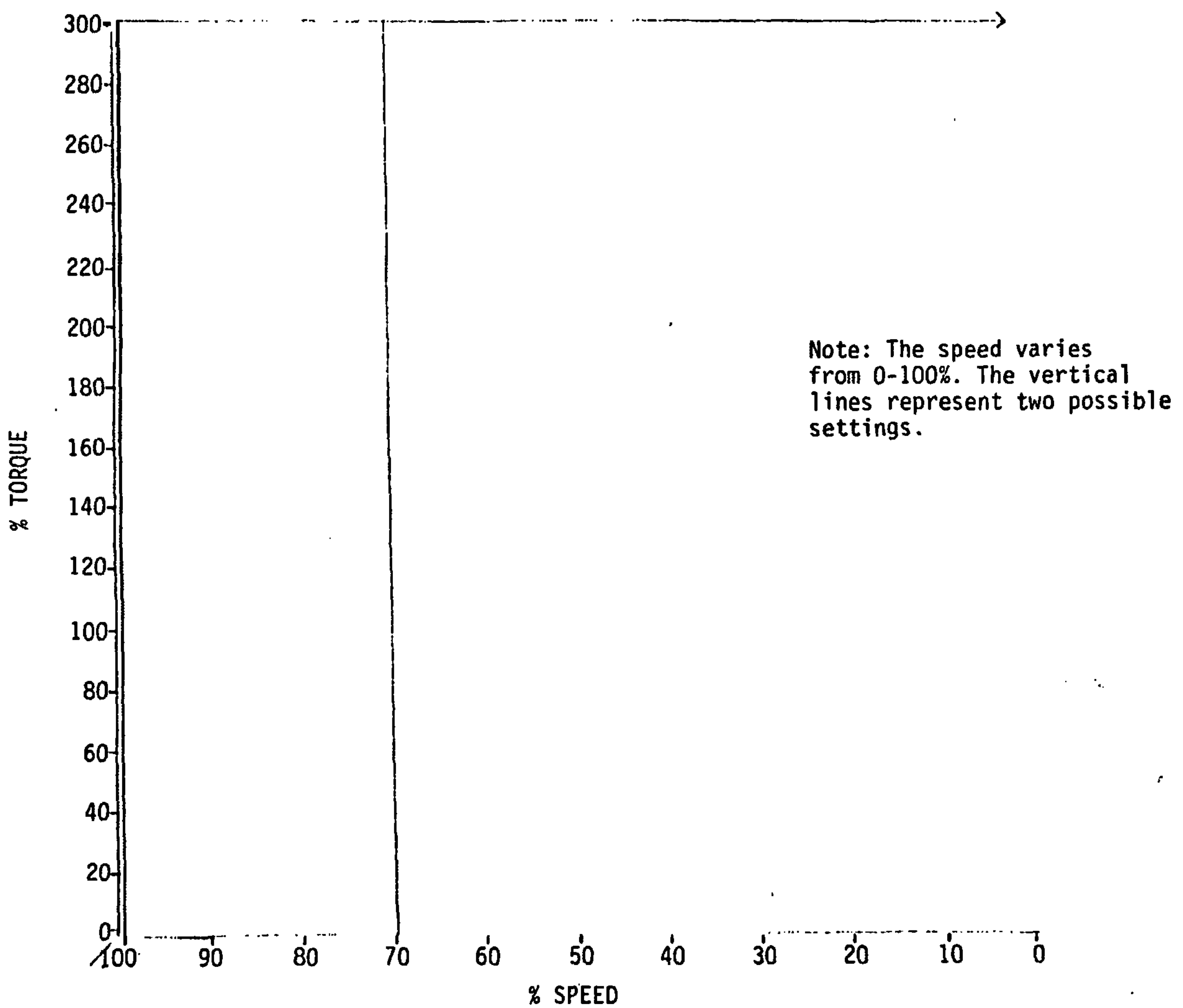

Figure 3
DC Motor Torque Speed Curve

b

Figure 4
AC Motor Torque Speed Curve

<u>Region I</u> – Constant angular velocity (DC Motor) Model

$\frac{d^2\theta}{dt^2} = 0$ and $\frac{d\theta}{dt} = w_0$

Equation (6) reduces to

$$J(t) = kNR^2\theta + NRP \quad (7)$$

or, in terms of T = tension in one cable

$$T = kR\theta + P \quad (8)$$

Since the angular velocity is constant

$$\theta = w_0 t \quad (9)$$

and

$$T = kRw_0 t + P \quad (10)$$

If J_r is the motor torque required to lift the design rated load, and "h" is the ratio of the limiting torque to the torque required to lift the design rated load, equation (7) yields the drum angle θ_1 at which the torque becomes constant.

$$\theta_1 = \frac{hJ_r - NRP}{kNR^2} \quad (11)$$

From equation (9) the drum angle reaches θ_1 at a time t_1

$$t_1 = \frac{\theta_1}{w_0} = \frac{hJ_r - NRP}{kNR^2 w_0} \quad (12)$$

Table F.3 describes the Region 1 solution for a ramp torque speed relationship, i.e., typical of AC motors.

<u>Region 2</u>

Once the torque limit is reached the form of the remaining solutions is the same, regardless of which of the two torque speed relationships was assumed in Region 1. For angles θ greater than or equal to θ_1 and times t greater than or equal to t_1, equation (6) becomes

$$\frac{d^2\theta}{dt^2} + \frac{nKR^2}{I}\theta = \frac{hJ_r}{I} - \frac{NRP}{I} \quad (13)$$

which can be written in terms of a natural frequency C

$$\frac{d^2\theta}{dt^2} + C^2\theta = \frac{hJ_r}{I} - \frac{NRP}{I} \quad (14)$$

where

$$C = \left(\frac{kNR^2}{I}\right)^{1/2} \tag{15}$$

The solution obtained for the conditions $\theta = \theta_1$, and $\frac{d\theta}{dt} = w_0$ at $t^* = 0$ where $t^* = t - t_1$ is

$$\theta = \frac{w_0}{C}\sin(Ct^*) + \frac{hJ_r - NRP}{IkNR^2} \tag{16}$$

The lead line tension for times after $t = t_l$ is therefore,

$$T = kR\theta + P \tag{17}$$

where the expression for θ in equation (16) is substituted into equation (17).

Summary

The tension in the lead lines is

$$T = kRw_0 t + P \qquad 0 < t < t_1 \tag{18}$$

$$= \frac{kRW_0}{C}\sin(Ct^*) + \frac{hJ_r}{NR} \qquad t \geq t_1, \text{i.e. } t^* \geq 0 \tag{19}$$

where

$$C = \left(\frac{kNR^2}{I}\right)^{1/2} \tag{20}$$

and

$$t_1 = \frac{\theta_1}{w_0} = \frac{hJ_r - NRP}{knR^2 w_0} \tag{21}$$

This analysis can be extended to represent the tension in the lead line and the stresses in the hoist machinery/girder structure following a load hangup, by accounting for the additional cable extended. The analysis can also be extended to dual drive train cranes by the appropriate adjustment of the effective moment of inertia. Cranes with multiple hoist drums can be analyzed with the same approach used herein.

5. Cable and Machinery loading Following a High Speed Two Blocking

Figure 5 illustrates the lead line tension in a dual reeved, single drive train, 130 Ton capacity hoist, which is not protected by an EATL, following a two blocking at rated speed. The equations, derived in Section 4, were evaluated using a FORTRAN IV program and the figure was generated by a CALCOMP Plotter. The scale for cable loading is on the right hand side of these figures. This

scale has been normalized to 90% of the wire rope yield strength. The scale for machinery loading is on the left hand side of these figures. It has been normalized such that the machinery loading is 1.0 when a design rated load is being hoisted.

For this calculation it has been assumed that the maximum torque that can be applied by the DC drive motor is 2.75 times the torque required to hoist the design rated load. This value represents an internal limit based on design constraints for voltage and current as determined by the manufacturer.

The following data were used in generating these figures:

$$k = \frac{.79\ x\ 12\ x\ 10^6}{80} = 118500\frac{lb}{ft}$$

$$A_r = .79\ in^2$$

$$y = 12\ x\ 10^6\ lb/in^2$$

$$R = 2.88\ ft$$

$$w_0 = .2189\ {}^{radian}/_{second}\ (rated\ motor\ speed, 1200\ RPM)$$

$$h = 2.75\ (no\ EATL)$$

$$P = \frac{260000}{(2)(8)}\frac{(1.04^7)(8)(1.04-1)}{(1.04^8-1)} = 18570\ lb$$

$$J_r = 128000\ ft-lb$$

$$L = 80\ ft$$

$$N = 2$$

$$n = 8$$

$$K = 1.04$$

$$I = 911000\ slug-ft^2$$

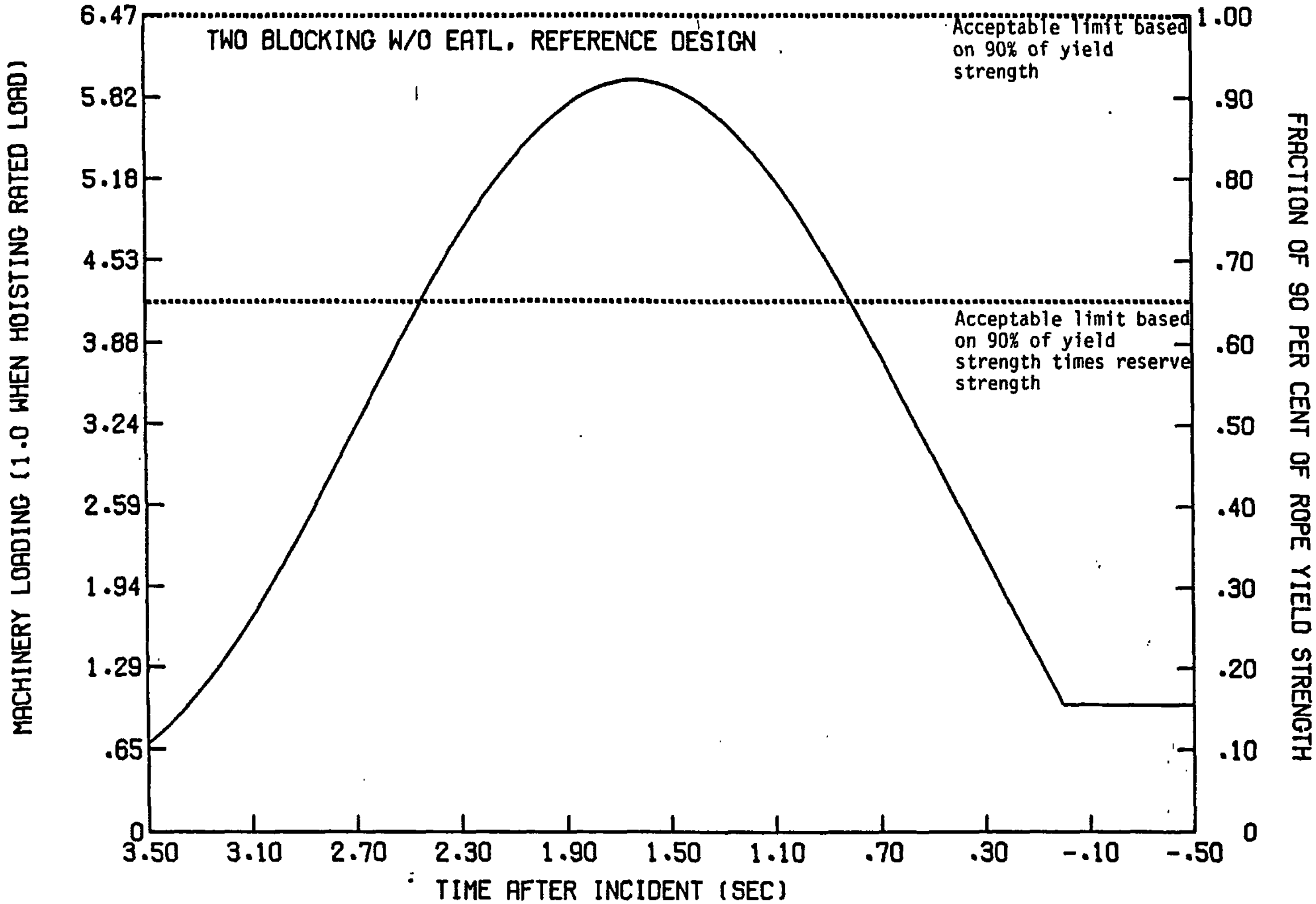

Figure 5
Two Blocking W/O EATL, Reference Design

6. Description of the Analysis of Cable and Machinery Loading Following Two Blocking of a Crane With an EATL

h. Introduction and Analysis

Section 4 provided an analysis of two blackings of conventional cranes without an EATL. This section extends that analysis by including an EATL in the drive train. As in Section 4, the analysis will be separated into two sections.

Region 1

[

]a,c

Region 2

[

]a,c

[

]a,c

b

Figure 6
Two Blocking W/EATL, Reference Design

b

Figure 7
Typical Hoist Drive System With EATL

i. Inclusion of Damping in the Analysis

[

]a,c

j. Region 3-Inclusion of Motor Shutdown in the Analysis

[

]a,c

[

]a,c

k. Inclusion of a Varying Spring Constant in the Analysis

[

]a,c

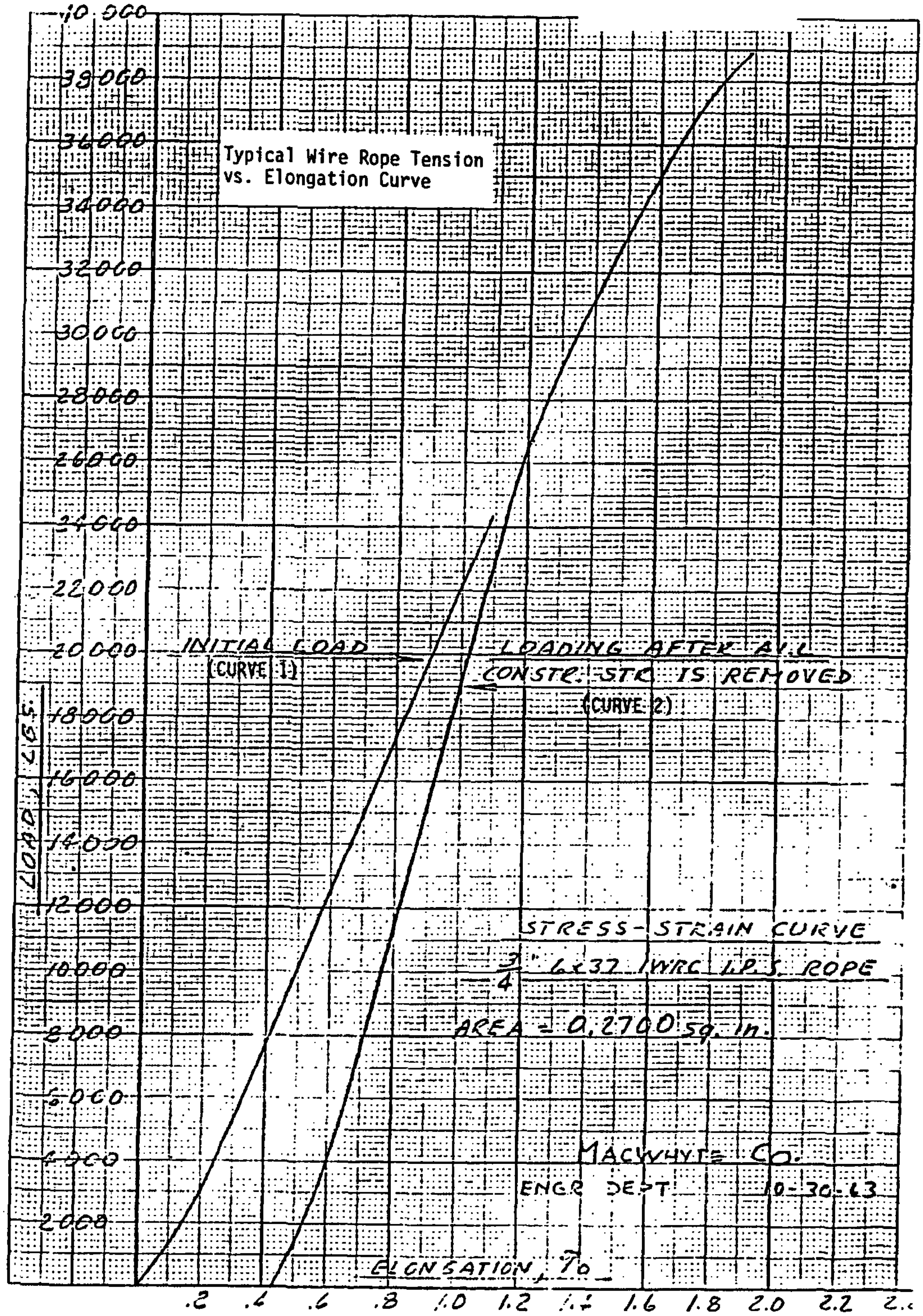

Figure 8
Typical Wire Rope Tension vs. Elongation Curve

7. Comparison of Actual Test Data Versus Analytical "Best Fit" for Cable loading Following Two Blocking With an (EATL)

The curve designated "Actual Test Curve" in Figure 9 represents the results of a shop two blocking test conducted as part of the LOFT hoist test program prior to delivery. The report "Summary of lessons learned in Retrofitting the New Trolley on the LOFT Containment Building Polar Crane" contains the outline used in conducting the shop two blocking tests.

The curve designated "Analytical Best Fit Curve" was generated by a CALCOMP plotter utilizing information from a FORTRAN IV computer program. This curve was generated selecting spring constants, damping coefficients, hysteresis effects and constructional stress effects with the express purpose of fitting the analytical solutions to the actual test data. Table F.1 lists the constants used for the analytical best fit curve. The "Original Value" column of Table F.1 indicates the expected values based on data gathered from the shop two blocking tests and manufacturer's product information. The "Original Values Changed to Achieve Best Fit Curve" column lists those values that were changed in order to "best-fit" the analytical, computer generated curve to the shop test curve.

b

Figure 9
Two Blocking Comparison, Actual Shop Test Data vs. Analytical Best Fit Curve

Table F.1
Best Fit Curve (Figure 9) Constants

Item	Original Design Value (unless otherwise annotated)	Values Changed to Achieve Best Fit Curve

a,c

Table F.1
Best Fit Curve (Figure 9) Constants (cont.)

Item	Original Design Value (unless otherwise annotated)	Values Changed to Achieve Best Fit Curve

a,c

b

Figure 10
Tension vs. Elongation Curve Illustrating Actual Spring Constants Used for Best Fit Curve

Table F.2
Tackle System Efficiency Derivation

When the load W is statically supported by multiple-part wire ropes, the load on each wire rope part is given by

$$T_s = \frac{W}{nN} \tag{33}$$

where T_s is the static tension in one part, W is the load, n is the number of parts of line in one rope, and N is the number of ropes. When hoisting, the effects of sheave friction and of bending a wire rope around a sheave cause the tension in each part of the rope to successively increase from the part attached to the dead end (part #4, Figure 1) to the lead line (part #1, Figure 1). The lead line tension while hoisting, P, is greater than the static tension in one part, T_s. P and T_s are related by an efficiency factor

$$E = \frac{T_s}{P} \tag{34}$$

where E is the tackle system efficiency.

E can be derived by starting with the expression for the tension in all of the wire rope parts

$$\frac{W}{N} = P + \frac{P}{K} + \frac{P}{K^2} + \frac{P}{K^3} + \frac{P}{K^4} + \ \ldots + \frac{P}{K^s} \tag{35}$$

where $\frac{W}{N}$ is the static tension in one rope, P is the tension in the lead line, all other terms represent the tension in the parts of rope moving away from the hoist drum, s is the number of rotating sheaves, and K is defined in Paragraph 3a(5).

Substituting the expressions for T_s equation (33), and P, equation (35) into equation (34) yields

$$E = \frac{\frac{W}{nN}}{\frac{W}{N\left(1+\frac{1}{K}+\frac{1}{K^2}+\frac{1}{K^3}+\frac{1}{K^4}+\ldots+\frac{1}{K^s}\right)}} \tag{36}$$

Now by cancellation, multiplying both numerator and denominator by $K^s(K-1)$, and noting that $n = s + 1$, the result is

$$E = \frac{K^n - 1}{K^s n(K-1)} \tag{37}$$

The expression for E, equation (37), is the same equation found in the "Catalog of Tables, Data and Helpful Information, G-17," MacWhyte Wire Rope Co., pg. 150. Other wire rope companies also use the same expression for E.

Substituting this expression for E into equation (34) and solving for P, yields the desired relation for initial lead line tension

$$P = \frac{(W)K^s n(K-1)}{(nN)(K^n-1)} = \frac{T_s}{E} \qquad (38)$$

Table F.3
Generic Solution for Hoist Motors With Ramp Type Torque Speed Characteristics

If a ramp type torque speed relationship is assumed, an equation for the time varying torque must be established. Given the torque speed relationship shown by Figure 4 for an AC motor, where J_f is the torque limit of the motor or EATL whichever is lower, w_0 is the initial speed, and w_f is the speed corresponding to the torque limit, the equation that defines the torque, J, for any speed between w_f and w_0 is:

$$J = \frac{J_f}{w_f - w_0}\left(w_0 - \frac{d\theta}{dt}\right) \tag{39}$$

Substituting this value for J into equation (6) yields

$$\frac{d^2\theta}{dt^2} + 2Z\frac{d\theta}{dt} + C^2\theta = \frac{J_f w_0}{(w_f - w_0)I} - \frac{NRP}{I} \tag{40}$$

For the initial conditions $\theta = 0$ and $\frac{d\theta}{dt} = w_0$ there are two solutions to equation (40) depending on the relationship of Z to C. The solution is comprised of exponentials when $Z^2 \geq C^2$ and is given by

$$\theta = \left(w_0 + \left(Z + (Z^2 - C\text{^}2)^{1/2}\right)\left(\frac{(w_f - w_0)NRP - J_f w_0}{(w_f - w_0)kNR^2}\right)\right)\left(\frac{exp\left(-Z + (Z^2 - C^2)^{1/2}\right)t}{2(Z^2 - C^2)^{1/2}}\right) - \left(w_0 + \left(Z + (Z^2 - C^2)^{1/2}\right)\left(\frac{(w_f - w_0)NRP - J_f w_0}{(w_f - w_0)kNR^2}\right)\right)\left(\frac{exp\left(-Z - (Z^2 - C^2)^{1/2}\right)t}{2(Z^2 - C^2)^{1/2}}\right) + \left(\frac{J_f w_0 - (w_f - w_0)NRP}{(w_f - w_0)kNR^2}\right) \tag{41}$$

The solution is comprised of trigonometric terms when $Z^2 < C^2$ and is given by

$$\theta = exp^{-Zt}\left(\frac{w_0 + Z\left(\frac{(w_f - w_0)NRP - J_f w_0}{(w_f - w_0)kNR^2}\right)}{(C^2 - Z^2)^{1/2}}\right) sin(C^2 - Z^2)^{1/2}t + exp^{-Zt}\left(\frac{(w_f - w_0)NRP - J_f w_0}{(w_f - w_0)kNR^2}\right) cos(C^2 - Z^2)^{1/2}t + \left(\frac{J_f w_0 - (w_f - w_0)NRP}{(W_f - W_0)kNR^2}\right) \tag{42}$$

This relationship can be used to determine the cable tension and torque. When the torque applied equals the limiting torque, the equations of Region 2 of Section 4 or Section 6 are applied as applicable.

Finally, when $(w_f - w_0) = 0$, the solution to equation (40) becomes

$$\theta = w_0 t \tag{43}$$

Equation (43) is the same solution for angular displacement as was assumed for a constant speed motor.

APPENDIX G
DESCRIPTION OF TOTALLY MECHANICAL DRIVE TRAIN CONTINUITY DETECTOR AND EMERGENCY DRUM BRAKE ACTUATOR

R.W. Holloran

C.A. Rusch

R.E. Morton

M.N. McDermott

REVISION 7

Assistance in Preparation Provided by:

HOLLORAN & ASSOCIATES
Mechanical and Nuclear Engineering Services
Suite 102
205 108th Ave NE

NOTICE

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Table of Contents and Revision Status for Appendix G

1 Introduction

1.1 The purpose of this Appendix is to describe the operation of the totally mechanical Emergency Drum Brake Actuator and its companion Drive Train Continuity Detector. The response to each of the failures described in Section E of the body of EDR-1 is described for a Hoist's Integrated Protective System (HIPS), which contains these two components. In addition the provisions for testing the totally mechanical Emergency Drum Brake Actuator and its companion Drive Train Continuity Detector are also defined.

1.2 Figure I is a schematic overview of a Typical X-SAM Crane Hoist System arrangement that is equipped with a totally mechanical Emergency Drum Brake Actuator and Drive Train Continuity Detector. The actual apparatus may be arranged differently in some respects, but the function, operation and operating environments are as shown. For the convenience of the reader the following overview of the remainder of the system is provided prior to the subsequent description of the Emergency Drum Brake Actuator, Drive Train Continuity Detector, and Failure Actuation and Monitoring Assembly.

1.3 A seismically qualified trolley or hoist frame supports a conventional crane duty motor and electrical load control (2), which are coupled to a gear case (3). The gearing may take a variety of forms, e.g., spur, helical, or planetary, depending upon the hoist arrangement. A single conventional crane duty high speed holding brake (4) is mounted on the high speed shafting. An Energy Absorbing Torque Limiter (EATL) assembly (5) is integral with the gearing. The wire rope drum may be either journaled in the gear case, as shown in Figure I, or may be driven through a bull gear by a pinion on the output shaft of the gear case. Motion of the wire rope drum following failure of the drum shaft, hub; or bearings is limited by the Drum Safety Support Structure (9) and the gear case, when the drum is journaled into the gear case. The Emergency Drum Brake Assembly (10) is located on the wire rope drum so that it can stop and hold the load in the event of a drive train failure. The various detectors in the Failure Detection System that actuate the Failure Actuation and Monitoring Assembly are described later in Section 4 of this Appendix.

b

Figure 1
General Assembly

Figure 2
List of Components

a,c

2 Emergency Drum Brake Actuator

2.1 A band brake is normally used with the totally mechanical Emergency Drum Brake Actuator, as shown in Figure 3. However, the totally mechanical Emergency Drum Brake Actuator is also compatible with a disk brake. The totally mechanical Emergency Drum Brake Actuator has the following basic functions:

45. Use energy from an external non-safety related source to release the Emergency Drum Brake

46. Store internally the energy needed set the Emergency Drum Brake in the event of a failure.

47. Release the energy from the storage device to set the Emergency Drum Brake in the event of a "failure." In this context, the term "failure" includes lack of continuity of the drive train, a failure in the continuity detector, or an error signal from the drum overspeed detector, the wire rope spooling monitor, or the backup upper travel limit switch, and continued lowering of the load A2 following a wire rope failure.

48. Not release the energy from the storage device and thus not set the Emergency Drum Brake when power to the crane is shut off, unless there is a failure, as defined above.

49. Manually lowering the load if required in the event of an emergency.

2.2 In the reference design these functions are accomplished by:

50. High pressure air compressing a spring in a spring chamber used to release the Emergency Drum Brake.

51. A "pelican hook" holding the compressed spring after the air pressure in the spring chamber is vented, allowing the drum to rotate, unless the Drive Train Continuity Detector detects a discontinuity between its input shafts, as is described in Section 3 of this Appendix. Alternatively, the Drive Train Continuity Detector described in Section 3 of this Appendix is capable of directly holding the compressed spring in low capacity hoists-generally I 0 Tons or less.

52. The Failure Actuation and Monitoring Assembly opening the mechanical link between the two input shafts to the Drive Train Continuity Detector, as is described in detail in Section 5 of this Appendix.

53. A manually controlled air valve pressurizing the spring chamber, thereby releasing some of the tension in the brake band – allowing the load to lower.

2.3 [

]a,c

[

]a,c

2.4 [

]a,c

2.5 [

]a,c

2.6 [

]a,c

2.7 [

]a,c

b

Figure 3
Emergency Drum Brake Actuator-Plan View

b

Figure 4
Emergency Drum Brake Actuator – Side View

b

Figure 4a
Emergency Drum Brake Actuator Operated Directly by Continuity Detector– Side View

3 Drive Train Continuity Detector

3.1 As is the case with the other types of Drive Train Continuity Detectors discussed in the main body of EDR-1, the totally mechanical Drive Train Continuity Detector is driven by both the lowest and highest speed shafts in the hoist so that any failure between the motor and wire rope drum will be detected. The totally mechanical Drive Train Continuity Detector has three basic functions:

54. Monitoring the ratio between the angular displacement of the motor and drum shafts and sense changes in this ratio that indicate there is a discontinuity in either the drive train or the inputs to the detector.

55. Mechanically nulling the accumulation of very small angular displacements between the motor and drum shaft that may result from a slight slippage of the EATL when the hoist stops.

56. Providing an output torque of sufficient magnitude to operate a release mechanism for the pelican hook in the totally mechanical Drum Brake Actuator.

3.2 In the reference design these functions are accomplished by:

57. A differential that is driven by the drum and the motor.

58. A mechanism in one of the inputs to the differential that provides an output from the differential that is always in the same direction during normal operation and the opposite direction in the event of a discontinuity between the inputs of the detector's differential.

59. A one way Sprag clutch that allows the differential's output shaft to turn freely under normal conditions, allowing the release mechanism to hold the totally mechanical Drum Brake Actuator. When the differential's output shaft rotates in the opposite direction, it drives the release mechanism out of engagement, releasing the totally mechanical Drum Brake Actuator.

3.3 As shown in Figure 5, the totally mechanical Drive Train Continuity Detector is essentially a rugged miniature crane duty gear box housed in a steel enclosure (63). In the reference design this enclosure is supported and torque mounted on an extension (80) of the drum shaft (41). The enclosure protects all of the components from the environment. The moving components of the detector operate in an oil bath. The components required to set the brake in the event of a drive train failure will either shutdown the hoist in the event of their failure during normal operation, or they are designed with a minimum 10: I factor of safety during normal operation and a 5: I factor of safety when the inertial forces of the worst case drive train hoist failure are considered. The components in the reference design that will not shutdown the hoist in the event of their failure during normal operations are identified with an "*" on Figure 2.

3.4 The following notation is used in all of the figures of this Appendix to identify the relative rotation of hoist and Drive Train Continuity Detector components:

60. indicates the direction of rotation while hoisting and
61. indicates the direction of rotation while lowering.

3.5 [

]^{a,c}

3.6 [

]^{a,c}

3.7 [

]^{a,c}

3.8 [

]^{a,c}

3.9 [

]a,c

3.10 [

]a,c

3.11 [

]a,c

b

Figure 5
Drive Train Continuity Detector

4 Failure Actuation and Monitoring Assembly

4.1 The purpose of the Failure Actuation and Monitoring Assembly (FAM) is to monitor the signals from the other detectors in the Failure Detection System and actuate the Emergency Drum Brake by creating a discontinuity in the high speed input to the Drive Train Continuity Detector.

4.2 In the reference design, an electric clutch (14) serves as the Failure Actuation and Monitoring Assembly. One side of the Failure Actuation and Monitoring Assembly is driven by a high speed shaft, shown in the reference design as the motor shaft (2). The other side of the Failure Actuation and Monitoring Assembly drives the flexible cable or line shaft (13) previously described in Section 3 of this Appendix, which provides the high speed input to the Drive Train Continuity Detector. The electric clutch is engaged when the hoist is energized. Each of the detectors in the Failure Detection System trips a limit switch that opens the electric circuit that engages the clutch. For convenience these detectors, the functions of which has been described in the main body of EDR-1, are also shown on Figure 6 and listed here:

62. Wire rope spooling monitor (11).
63. Drum overspeed detector (16).
64. Rope break detector (21).
65. Backup upper travel limit (not shown).
66. Brake Actuation Detector (28).

4.3 De-energizing the electric clutch creates a discontinuity in the high speed input to the Drive Train Continuity Detector. This discontinuity will be detected by the Drive Train Continuity Detector after the load starts to lower a small amount.

b

Figure 6
Failure Actuation and Monitoring Assembly

5 Single Failure Analysis of Totally Mechanical Emergency Drum Brake and Drive Train Continuity Detector

Section III.E of the body of EDR-1 describes the overall response of a crane or hoist equipped with a Hoist's Integrated Protective System (HIPS) to eleven different incidents. The purpose of this section is to identify how the commitments of Section E are implemented by a HIPS that includes a totally mechanical Emergency Drum Brake Actuator and Drive Train Continuity Detector. Unless otherwise indicated, all part numbers are shown on Figure 5.

5.1 Overload – Similar to all X-SAM cranes, the EATL (item 5 of Figure I) starts slipping when its pre-set torque capability is exceeded during an overload. [

]^{a,c}

5.2 Load Hangup – A HIPS', which includes a totally mechanical Emergency Drum Brake Actuator and Drive Train Continuity Detector, response to a load hangup is the same as its response to an overload.

5.3 Two Blocking – A HIPS', which includes a totally mechanical Emergency Drum Brake Actuator and Drive Train Continuity Detector, response to a two blocking is the same as its response to an overload.

5.4 Hoist Drive Train Failure – [

]^{a,c} Power is removed from the hoist when the Emergency Drum Brake actuates by opening a limit switch (item 28 of Figure 4). In previous designs of HIPS the Drum Overspeed Detector detected and actuated the Emergency Drum Brake substantially before the Drive Train Continuity Detector could detect a change in the ratio of the high and low speed shafts. However, in the event of a drive train failure, the totally mechanical Emergency Drum Brake Actuator and Drive Train Continuity Detector will detect and actuate the Emergency Drum Brake faster than the Drum Overspeed Detector. Furthermore, totally mechanical Emergency Drum Brake Actuator and Drive Train Continuity Detector, generally provide overall faster response times to drive train failures than previous systems, as measured by the maximum load displacement and kinetic energy of the load.

5.5 Drum Support Failure – Following a drum support failure, the drum will be safely held by the Drum Safety Structure, which is functionally identical to the ones shown in Section D.4 of the main body of EDR-1. In the reference design shown in Figure I, the hoist gear case (8) also functions as a Drum Safety Support of the alternate design described in Section D.4 of the main body of EDR-1.

5.6 Overspeed – Overspeed following a control system failure is sensed by the motor overspeed detector (not shown). A control system failure may prevent the high speed holding brakes from engaging. Therefore, a separate drum overspeed detector removes power to Failure Actuation and Monitoring Assembly (FAM), which causes the Emergency Drum Brake to set. Since the function of the Overspeed Detector is less critical when a totally mechanical Emergency Drum Brake Actuator and Drive Train Continuity Detector is used, only one Overspeed Detector is required.

5.7 Total Loss of Power While Hoisting a Critical Load – As in all X-SAM Cranes, a total loss of electrical power sets the conventional high speed holding brake, thereby stopping the load. However, unless the high speed holding brake fails to hold the load the Emergency Drum Brake will not set. Since a total loss of electric power disconnects the Failure Actuation and Monitoring Assembly, the Drive Train Continuity Detector will actuate the Emergency Drum Brake as soon as the load starts lowering for any reason.

Emergency lowering without power is accomplished by manually locking holding brake (item 4 of Figure I) open, which will automatically set the Emergency Drum Brake (10) since the Failure Actuation and Monitoring Assembly is deenergized. As shown in Figure 4, to start lowering the load the air valve (27), which admits pressurized air to the spring chamber (25), is cracked open-pressurizing the spring chamber (25), thereby releasing some of the tension in the brake band (24). A mechanical tachometer can be used on one of the high speed shafts to monitor the lowering speed. The lowering speed is modulated with the air valve by adjusting the air pressure in the spring chamber. At any time during the manual lowering of the load, the operator can release the valve handle, which vents the air pressure in the spring chamber, setting the Emergency Drum Brake. The Actuator cannot return to the battery position during a manual lowering operation because the Failure Actuation and Monitoring Assembly is still de-energized so that the Drive Train Continuity Detector will actuate the release mechanism as soon as it starts to reset.

5.8 Hoist Control System Failure – A HIPS, which includes a totally mechanical Emergency Drum Brake Actuator and Drive Train Continuity Detector, responds to a hoist control system failure in the same manner as is described in Section E.8 of the main body of EDR-1.

5.9 Off Center Lifts – In the event an excessive off center lift is made, the Wire Rope Spooling Monitor senses the improper spooling of the wire rope before damage can occur. The monitor (item 11 of Figure 6) removes power from the Failure Actuation and Monitoring Assembly, and the hoist motor controls through a relay. A key is required to reset the relay, so the hoist cannot be restarted until the problem is remedied and management concurrence obtained.

5.10 Failure of High Speed Motor Holding Brakes – The Emergency Drum Brake System provides a backup to the conventional holding brake during normal operations, since it automatically actuates on overspeed. The Emergency Stop Button removes power from the Failure Actuation and Monitoring Assembly, permitting the operator to manually engage the Emergency Drum Brake.

5.11. Cable Failure – As shown in Figure 6, failure of either wire rope opens a travel limit or hydraulic pressure switch (21) in response to the resultant movement of the Equalizer Arm (20). The monitor removes power from the Failure Actuation and Monitoring Assembly, and the hoist motor controls through a relay. A key is required to reset the relay, so the hoist cannot be restarted until the problem is remedied and management concurrence obtained.

6. Special Test Provisions for the Totally Mechanical Emergency Drum Brake Actuator and Its Companion Drive Train Continuity Detector

6.1 The testing identified by Section G.3.b and c is modified in the following ways to account for the special characteristics of the totally mechanical Emergency Drum Brake.

67. Test of the Actuator – The time required for the Emergency Drum Brake to engage, following action by the Failure Detection System, is measured with an oscillograph. During pre-operational and periodic testing, the drum brake is manually actuated to verify that all power to the crane is interrupted when it engages.

68. Test of the Drive Train Continuity Detector – Proper operation of the Drive Train Continuity Detector is verified by the brake setting when the EATL actuates during the slow speed two blocking test.

69. Test of the Failure Actuation and Monitoring Assembly – During pre-operational and periodic testing, the Failure Actuation and Monitoring Assembly is manually de-energized. Then the hoist is lowered to verify that the brake will set as soon as the load starts lowering when the Failure Actuation and Monitoring Assembly is actuated.

APPENDIX H
DESCRIPTION OF CONTINUOUSLY ENGAGED EMERGENCY DRUM BRAKE SYSTEM

REVISION 7

Assistance in Preparation Provided by:

HOLLORAN & ASSOCIATES
Mechanical and Nuclear Engineering Services
Suite 102
205 108th Ave NE

NOTICE

Table of Contents and Revision Status for Appendix H

Table of Contents and Revision Status for Appendix H (cont.)

1. Introduction

1.1 The purpose of this Appendix is to describe the operation of the continuously engaged Emergency Drum Brake and its integral Drive Train Continuity Detector. This system provides the inherent safety of a worm drive, with the efficiency of a non-worm gear drive. The response to each of the failures described in Section E of the body of EDR-1 is described for a Hoist's Integrated Protective System (HIPS), which contains these two components.

1.2 Figure 1 illustrates the reference design of the continuously engaged Emergency Drum Brake System. The actual apparatus may be arranged differently in some respects, but the function, operation and operating environments are as shown. For the convenience of the reader the following overview of the remainder of the system is provided prior to the subsequent description of the continuously engaged Emergency Drum Brake System with its integral Drive Train Continuity Detector, and the Failure Actuation and Monitoring Assembly.

1.3 A seismically qualified trolley or hoist frame (1) supports a conventional crane duty motor and electrical load control (2), which are coupled to a gear case (3). The gearing may take a variety of forms, e.g., spur, helical, or planetary, depending upon the hoist arrangement. A single conventional crane duty high speed holding brake (4) is mounted on one of the high speed shafts. An Energy Absorbing Torque Limiter (EATL) assembly (5) is integral within the gear case (3). The wire rope drum (6) may be either journaled in the gear case, as shown in Figure I, or may be driven through a bull gear by a pinion on the output shaft of the gear case. Motion of the wire rope drum following failure of the drum shaft, hub, or bearings is limited by the worm housing! Drum Safety Support Structure (9) and the gear case register (8) when the drum is journaled into the gear case. The Emergency Drum Brake Assembly engages the end of the wire rope drum opposite from the end of the hoist drum that is driven by the hoist drive train. This configuration has been selected so that the Emergency Drum Brake will stop and hold the load in the event of a drive train failure. The various detectors in the Failure Detection System that actuate the Failure Actuation and Monitoring Assembly are described later in Section 4 of this Appendix.

b

Figure 1
General Assembly

b

Figure 1A
Alternate General Assembly

Figure 2
List of Components

a,c

2 Continuously Engaged Emergency Drum Brake System

2.1 The continuously engaged Emergency Drum Brake System utilizes a worm wheel integral with the drum. It also includes a worm driven by a motor, or typical crane high speed shaft. Alternatively, the worm can be driven by a separate electric motor. The worm has a non-reversing gear ratio. Therefore, the worm wheel, and thus the drum, cannot rotate at a different rate or in a direction opposite to that in which the worm is being driven, as would occur during a drive train failure. In order to effectively function as an Emergency Drum Brake:

70. The worm must also stop the hoist drum in response to error signals from the drum

71. overspeed detector, the wire rope spooling monitor, and the backup upper travel limit switch, and if load continues to lower following a single wire rope failure;

72. The loads imposed on the worm and worm wheel by the kinetic energy of the drive train and the load must be limited to a safe level when the worm stops rotating in response to an error signal while hoisting or lowering at the rated speed; and

73. There must be provisions for manually lowering the load.

2.2 In the reference design these functions are accomplished by:

74. The Failure Actuation and Monitoring Assembly opening the mechanical link between the motor and the worm in response to an error signal, as is described in detail in Section 4 of this Appendix. Alternatively, the Failure Actuation and Monitoring Assembly removes power from the worm drive motor in response to an error signal.

75. The EATL dissipating the high speed kinetic energy of the high speed components of the hoist drive train.

76. The worm and worm wheel being designed to safely absorb the kinetic energy of the load, the drum, and the drive train components between the drum and the EATL, as is described in Section 3 of this Appendix.

77. The worm and worm wheel assembly being designed to withstand forces imposed by the overhauling of the rated load overhaul and the maximum torque that the EATL allows the motor to impose.

78. A drive provided on the worm shaft to allow lowering the load in the event of a total loss of power.

2.3 As will be shown in Section 5 of this Appendix, the worm wheel, the worm and their supporting structure are considered key items of the continuously engaged Emergency Drum Brake System. The emergency load path is always engaged and the ancillary apparatus only allows the hoist system to operate. Reaction time is also not a factor, since the emergency load path is always in

position to stop the load after a small amount of load motion. Failure of any parts other than the load supporting elements results in a safe shutdown.

2.4 [

]a,c

3 Drive Train Continuity Detector

3.1 Ideally the rotation rates of the worm and worm wheel would be set exactly at the rates required for them to stay in mesh, without contact during normal operations. However, gear backlash and EATL creep could accumulate to the point that either the worm could lock on the worm wheel-stopping the hoist, or the worm could start driving the drum instead of the drive train, reducing the hoist's efficiency. High tooth tangential friction may also result when the worm wheel rotates against the stationary worm following reversal of the direction of drum, since the worm will not be driven until all of the backlash has been taken out of the drive train and the drive train continuity detector. To avoid these unacceptable conditions, the integral Drive Train Continuity Detector is designed to serve four basic functions:

79. Limiting the motor torque transmitted to the worm;
80. Nulling out the effects of gear backlash and accumulated EATL creep;
81. Limiting the tangential tooth friction between the worm and worm wheel during normal operations; and
82. Driving the worm out of engagement with the worm wheel after the direction of drum rotation is reversed.

3.2 In the reference design these functions are accomplished by:
[

]a,c

[

]a,c

3.3 [

]a,c

3.4 [

]a,c

3.5 [

]a,c

b

Figure 3
Drive Train Continuity Detector

4 Failure Actuation and Monitoring Assembly

4.1 The purpose of the Failure Actuation and Monitoring Assembly (F AM) is to monitor the signals from the other detectors in the Failure Detection System. When the Failure Actuation and Monitoring Assembly receives an error signal it creates a discontinuity in the high speed input to the Drive Train Continuity Detector. This discontinuity will be detected by the Drive Train Continuity Detector as soon as the load starts to lower or raise.

4.2 In the reference design, an electric clutch (14) serves as the Failure Actuation and Monitoring Assembly. One side of the Failure Actuation and Monitoring Assembly is driven by a high speed shaft, shown in the reference design as the motor shaft (2). The other side of the Failure Actuation and Monitoring Assembly drives the torque limiting device (80) previously described in Section 2 of this Appendix. This device provides the high speed input to the Drive Train Continuity Detector. The electric clutch is engaged when the hoist is energized. Each of the detectors in the Failure Detection System trips a limit switch that opens the electric circuit that engages the clutch. De-energizing the electric clutch creates a discontinuity in the high speed input to the Drive Train Continuity Detector. For convenience these detectors, the functions of which has been described in the main body of EDR-1, are also shown on Figure 4 and listed here:

83. Wire rope spooling monitor (II).
84. Motor overspeed detector (98).
85. Rope break detector (21).
86. Backup upper travel limit (not shown).
87. Drum Brake Actuator Switch (97).

Alternatively, the function of the Failure Actuation and Monitoring Assembly can be fulfilled by a relay in the control circuit for the worm drive motor. Each of the detectors in the Failure Detection System trips a limit switch that opens the relay. De-energizing this motor stops the high speed input shaft to the Drive Train Continuity Detector.

b

Figure 4
Failure Actuation and Monitoring System

5 Single Failure Analysis of Continuously Engaged Emergency Drum Brake System

Section E of the body of EDR-1 describes the overall response of a crane or hoist equipped with a Hoist's Integrated Protective System (HIPS) to eleven different incidents. The purpose of this section is to identify how the commitments of Section 11I.E are implemented by a HIPS that includes a continuously engaged Emergency Drum Brake. Unless otherwise indicated, all part numbers are shown on Figure I.

5.1 Overload – Similar to all X-SAM cranes, the EATL (5) starts slipping when its pre-set torque capability is exceeded during an overload. However, when a continuously engaged Emergency Drum Brake is used, the Drive Train Continuity Detector is insensitive to discontinuities in which both the drum and the motor are rotating in the hoisting direction and the motor's relative rate of rotation is faster than that of the drum. In order to detect such discontinuities would require an additional Drive Train Continuity Detector of the type described in Appendix G. The only function of this detector would be to detect EATL slippage when the drum is rotating in the hoisting direction. The load is protected by the worm, even if the EATL fails to hold the load following an overloading incident. Therefore, the additional complication of another Drive Train Continuity Detector is not warranted.

5.2 Load Hangup – A HIPS equipped with a continuously engaged Emergency Drum Brake has the same response to a load hangup as to an overload.

5.3 Two Blocking – A HIPS equipped with a continuously engaged Emergency Drum Brake has the same response to a two blocking as to an overload. The backup upper limit switch will detect the two blocking. The backup upper limit switch will remove power from the Failure Actuation and Monitoring Assembly (14), and the hoist motor controls through a relay. A key is required to reset the relay, so the hoist cannot be restarted until the problem is remedied and management concurrence obtained.

5.4 Hoist Drive Train Failure – The drum accelerates in the lowering direction and is immediately stopped by the worm (83) when it contacts the worm wheel (82). The Emergency Drum Brake System is sized to absorb the kinetic energy of all elements below the EATL. Torque limiting device (80) protects the worm drive system from overtorque. In addition any failure in the input to the Drive Train Continuity Detector also stops the load. Translation of the carrier assembly in either direction actuates switch (97), removing power from the Failure Actuation and Monitoring Assembly (14), and the hoist motor controls through a relay. A key is required to reset the relay, so the hoist cannot be restarted until the problem is remedied and management concurrence obtained.

5.5 Drum Support Failure – Following a drum support failure, the drum will be safely held by the Drum Safety Structure. As shown in Figure I, the hoist gear case (8) and the housing (9) function are functionally identical to the alternative shown in SectionD.4 of the main body of EDR-1. Alternatively, a Drum Safety Support of the other design described in Section D.4 of the main body of EDR-1 can be used.

5.6 Overspeed – Overspeed, following a control system failure, is sensed by the motor overspeed detector (98). A control system failure may prevent the high speed holding brake from engaging. Therefore, the drum overspeed detector removes power to Failure Actuation and Monitoring Assembly, which stops the drum in the manner described above. Because the Emergency Drum Brake is continuously engaged a Drum Overspeed Detector is not required.

Alternatively, inherent overspeed protection is provided by a separately driven Drive Train Continuity Detector, since the worm wheel and hence the drum's rate of rotation is limited by the rate at which the worm is driven. Since overhauling loads cannot be imposed on the worm, its speed is controlled by the constant speed drive motor.

5.7 Total Loss of Power While Hoisting a Critical Load – As in all X-SAM Cranes, a total loss of electrical power sets the conventional high speed holding brake, thereby stopping the load. However, unless the high speed holding brake fails to hold the load the Emergency Drum Brake will not set. A total loss of electric power disconnects the Failure Actuation and Monitoring Assembly, or alternatively de-energizes the separate motor that drives the worm. Therefore, if for any reason the load starts lowering, the Emergency Drum Brake will stop the drum after only a small amount of drum rotation has occurred. Emergency lowering without power is accomplished by releasing the conventional high speed holding brake (4) and rotating the worm (83) using an air motor or other auxiliary device on the external hex drive (98).

5.8 Hoist Control System Failure – A HIPS, which includes a continuously engaged Emergency Drum Brake responds to a hoist control system failure in the same manner as is described in Section E.8 of the main body of EDR-1.

5.9 Off Center Lifts – In the event an excessive off center lift is made, the Wire Rope Spooling Monitor senses the improper spooling of the wire rope before damage can occur. The monitor (II) removes power from the Failure Actuation and Monitoring Assembly, and the hoist motor controls through a relay. A key is required to reset the relay, so the hoist cannot be restarted until the problem is remedied and management concurrence obtained.

5.10 Failure of High Speed Motor Holding Brakes – The continuously engaged Emergency Drum Brake System provides a backup to the conventional holding brake during normal operations, since it is always in a position to stop the load. The Emergency Stop Button removes power from the Failure Actuation and Monitoring Assembly, permitting the operator to manually set the Emergency Drum Brake.

5.11 Cable Failure – As shown in Figure 4, failure of either wire rope opens a switch (21) in response to the resultant movement of the Equalizer Arm (20). The monitor removes power from the

Failure Actuation and Monitoring Assembly, and the hoist motor controls through a relay. A key is required to reset the relay, so the hoist cannot be restarted until the problem is remedied and management concurrence obtained.

6 Special Test Provisions for 'the Continuously Engaged Emergency Drum Brake System

The testing identified by Section G.3.b and c is modified in the following ways to account for the special characteristics of the Continuously Engaged Emergency Drum Brake System:

6.1 Test of the Drive Train Continuity Detector – During pre-operational and periodic testing, the Failure Actuation and Monitoring Assembly is manually de-energized. Then the hoist is lowered to verify that the brake will set as soon as the load starts lowering when the Failure Actuation and Monitoring Assembly is actuated. This test verifies proper operation of the Drive Train Continuity Detector.

6.2 Test of the Actuator – During pre-operational and periodic testing, proper operation of the Emergency Drum Brake Actuator is also verified during the test of the Drive Train Continuity Detector that is described above.

6.3 Test of the Failure Actuation and Monitoring Assembly – During pre-operational and periodic testing, proper operation of the Failure Actuation and Monitoring Assembly is also verified during the test of the Drive Train Continuity Detector that is described above.

APPENDIX I
ANALYSIS OF LOAD MOTION AND CABLE LOADING FOLLOWING A WIRE ROPE FAILURE IN AN X-SAM TYPE CRANE EQUIPPED WITH A TOTALLY MECHANICAL DRIVE TRAIN CONTINUITY DETECTOR AND EMERGENCY DRUM BRAKE ACTUATOR OR A CONTINUOUSLY ENGEGED EMERGENCY DRUM BRAKE SYSTEM

R.W. Holloran

REVISION 7

Amendment 7

Assistance in Preparation Provided by:

HOLLORAN & ASSOCIATES
Mechanical and Nuclear Engineering Services
Suite 102
205 108th Ave NE

NOTICE

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Table of Contents and Revision Status for Appendix I

0 References

F. Holloran and Associates Report, "Analysis of Load Motion and Cable Loading Following a Single Drive Train Failure or Wire Rope Failure in an X-SAM Type Crane," Revision 2, February 1980.

G. Holloran & Associates Report, "Analysis of Cable and Machinery Loadings Following Two Blockings of X-SAM Type Cranes," Revision 2, February 1980.

1 Introduction

The purpose of this report is to extend the analytical and numerical techniques for evaluating the consequences of a single wire rope failure that were previously developed in reference (a). The wire rope failure analysis described in reference (a) was restricted to one in which the wire rope drum and equalizer was held stationary throughout the load transfer from the failed to the intact reeving. This limitation was consistent with the type of emergency drum brakes and failure detection systems developed up to that time and the fact that a single wire rope failure was not the limiting failure in terms of load motion or kinetic energy.

With previous designs, the failure detection system quickly set the emergency drum brake before the torque limit of the energy absorbing torque limiter could be exceeded during a postulated wire rope failure – preventing drum rotation. With the recently developed designs, i.e., the totally mechanical drive train continuity detector and emergency drum brake actuator and the continuously engaged emergency drum brake system, a small amount of drum rotation is required to set the emergency drum brake. Therefore, the previous wire rope failure analysis must be extended to account for the additional load motion and kinetic energy associated with this drum rotation.

Furthermore, the response time of the new designs to a drive train failure is typically faster than the previous systems' response times. Therefore, the load excursion and load kinetic energy associated with a single wire rope failure may be the limiting failure with regards to the provisions that must be taken at the facility to accommodate the maximum load motion and kinetic energy from a postulated single failure in the crane handling system. Specifically, with previous designs, the load motion and kinetic energy associated with a design basis drive train failure exceeded that associated with a single wire rope failure. Therefore, a wire rope failure while lowering the design rated load at the design rated speed was not analyzed. Since the single wire rope failure may represent the worst case load motion and kinetic energy, it is considered prudent to evaluate the load motion and kinetic energy following a wire rope failure while lowering the load at the design rated speed rather than with a stationary drum, when a totally mechanical drive train continuity detector and emergency drum brake actuator, or a continuously engaged emergency drum brake system, is used.

Previously, the hydraulic equalization system prevented motion of the equalizer by creating a hydraulic lock following a wire rope failure. However, in some applications, a shock absorber is used in the hydraulic equalization system that allows the equalizer to slowly rotate into contact

with a structural member. Therefore, the analysis of the load motion and load kinetic energy following a wire rope failure also accounts for constant angular velocity equalizer motion.

As was the case with the previous analyses described in reference (a), the complete solution for a wire rope failure cannot be expressed in a simple form. Therefore, a computer program has again been used to obtain numerical results.

Section 3 explains the mathematical model used. This model is essentially the same as described in reference (a). Expressions for the displacement and kinetic energy of the load, as a function of time following the failure, are developed in Sections 4 and 5. These expressions, which are very similar to those developed in reference (a), provide a basis for evaluating the consequences of a wire rope failure on the equipment and structures under the load.

2 Approach

The analysis starts with the equations of motion for the following two general cases: (1) the wire rope drum and equalizer are rotating at constant rates (a stationary drum and equalizer represents a special case of this general solution, since their speed is still constant, albeit zero), and (2) the wire rope drum is being retarded by a friction brake or an energy absorbing torque limiter and the equalizer is rotating at a constant rate. See Figure 1 for a diagram of the hoist model used in deriving the equations.

The solutions given for these general cases are valid only for specific periods. To obtain complete solutions for all times of interest, the problems are divided into a series of time regions in which the appropriate physical conditions are properly modeled by one of the general solutions. The relevant general solution is applied to each of these time regions in turn.

The solutions of the general cases are sufficiently complicated to make the complete expressions for load displacement, velocity, etc., intractable if the formal expressions for these quantities at the end of each region are used for the initial conditions of the next region. To get around this difficulty, the solutions are evaluated numerically one region at a time. Appropriate tests are used, when necessary, in the numerical solutions to determine the time when one region ends and another starts. The numerical results calculated for the end of a region provide the initial conditions for the numerical solution in the following region.

Just before the wire rope failure, it is assumed that the motor is rotating the drum at a constant angular velocity, which is moving the load at a constant speed. With either type of the new designs, the sequence of events that follow a wire rope failure typically include:

88. Drum rotation at a constant angular velocity until the motor is de-energized. The shock absorber in the hydraulic equalization system permits the equalizer to start rotating at a constant angular velocity, with an attendant lowering of the load.

89. The motor is de-energized. It is assumed that there will be no retarding torque until the motor holding brake starts to engage.

90. The third region starts when the motor holding brake starts to engage. (As explained in section 3.c, the motor holding brake is assumed to increase linearly with time up to a maximum level.)

91. The maximum motor holding brake retarding torque is reached. (The kinetic energy of the motor and drum is absorbed by this constant retarding torque.)

92. The drum stops rotating. (The tension in the intact reeving builds up as the load's gravitational potential energy is converted to kinetic energy and then mechanical energy in the stretched wire ropes.)

93. The energy absorbing torque limiter starts slipping because the torque imposed on the drum by the tension in the lead line of the reeving exceeds the static torque setting of the energy absorbing torque limiter. (It is assumed that the torque limiter imposes a constant retarding torque on the drum.)

94. The drum stops rotating because either the tension in the wire rope has decreased below the dynamic slipping torque' of the energy absorbing torque limiter or there has been sufficient drum rotation, since the failure actuation and monitoring assembly was disengaged, for the emergency drum brake to be engaged. (The load will continue to oscillate in response to the Hooke's Law forces imposed by the elastic wire ropes until viscous forces damp out the oscillations. The analysis of Section 7 of reference (a) can be used if these viscous forces are to be included in the analysis.)

95. The equalizer rotates into contact with a structural member, which stops further rotation. (Depending upon the shock absorber design, the equalizer may come into contact with a structural member during regions (1) to (7). If it did, the region in which the equalizer stopped rotating is subdivided into two regions, one in which the equalizer is rotating, and one in which it has stopped.)

The exact sequence and duration of these events may vary depending upon the type of motor holding brake and controls that are specified by the Applicant for the crane. However, these differences are readily accounted for, since the same general equations remain valid – only the sequence of their use and the initial conditions need to be changed to account for the variations.

3 Description of Mathematical Model

This section describes the mathematical model of the hoist that is used to derive the general solutions and to link them to obtain the specific solutions for individual cases.

I. Model of Crane

Figure 1 shows a typical reeving arrangement, the pertinent physical parameters, and the sign conventions used. The following assumptions made in reference (a) remain valid:

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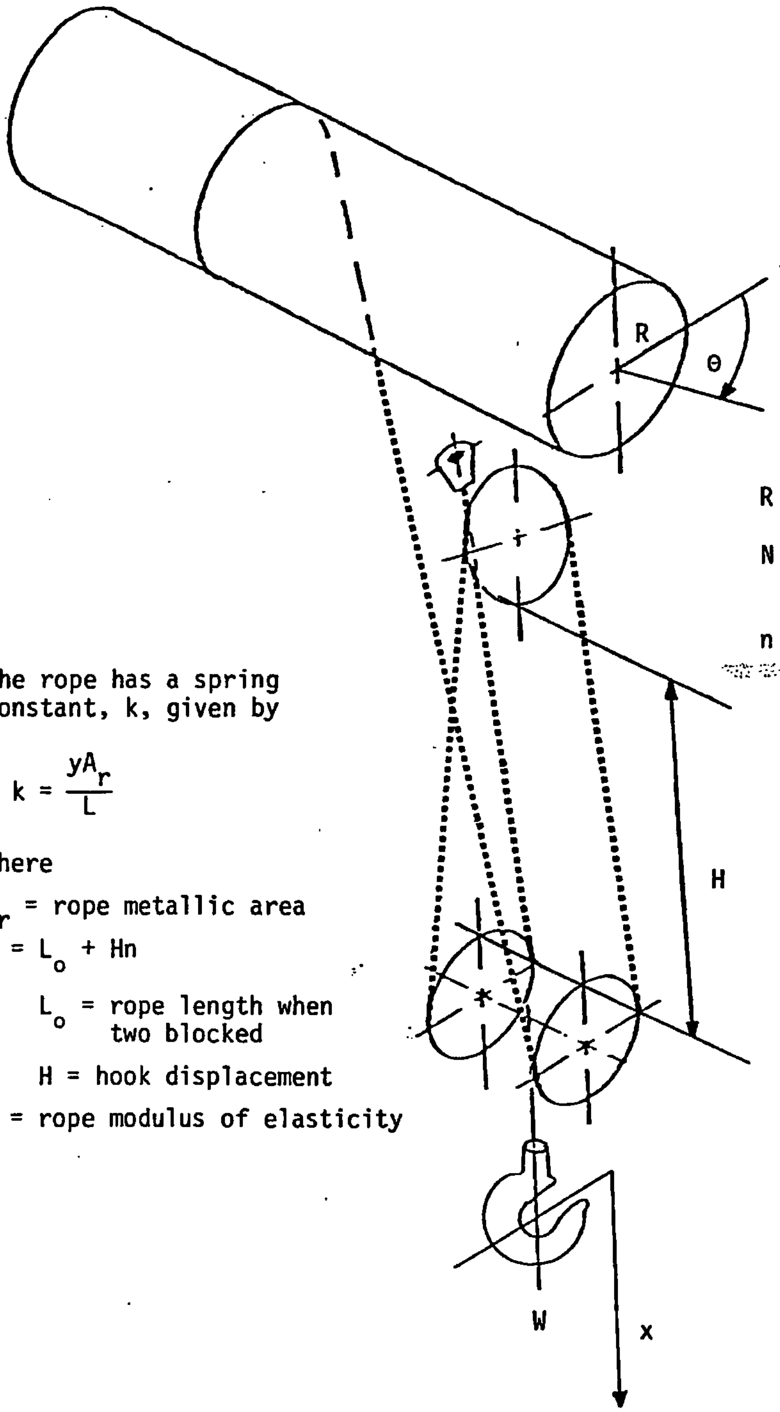
][a,c]



R = drum radius

N = number of ropes attached to Drum and Equalizer

n = number of parts of line in one rope

The rope has a spring constant, k, given by

$$k = \frac{yA_r}{L}$$

where

A_r = rope metallic area

$L = L_o + Hn$

L_o = rope length when two blocked

H = hook displacement

y = rope modulus of elasticity

Figure 1
Typical Reeving System

m. Model of Rope Break Detection System

It is assumed that after a known time delay the rope break detector will de-energize the hoist motor and after an additional time delay after the hoist motor is de-energized, the hoist motor brake will start engaging. In addition, after a known time delay, the rope break detector will de-energize the failure actuation and monitoring assembly in the input to the drive train continuity detector. After a known time delay, it is then assumed that the failure actuation and monitoring assembly will create a discontinuity in the input to the drive train continuity detector, which will then be detected by the drive train continuity detector, which is set to actuate when the drum and motor become out of phase by a given drum angle. Once this out-of-phase condition exists, it is assumed that the emergency drum brake will start actuating after a constant time interval. (Normally, it is expected that there will be insufficient drum rotation for the drum brake to engage following a rope break, unless for some reason the hoist motor brake does not engage.)

n. Model of Emergency Drum Brake and High Speed Holding Brake

Ederer Incorporated provided Holloran &Associates with the following information and assumptions regarding the performance of the emergency drum brake and the high speed holding brake:

4. The brakes apply a constant retarding torque (which may be zero) prior to actuation.
5. Upon its actuation, each brake applies a linearly increasing braking torque until the maximum braking is achieved.
6. After reaching the maximum, the braking torque remains constant until the drum stops.
7. The dynamic braking torque is independent of drum speed and can be replaced by the static braking torque once the drum stops.
8. The brakes' torque can be characterized as a multiple of the torque imposed on the drum by the design rated load.

o. Model of Hydraulic Equalization System

The reference design hydraulic load equalization system is assumed to function such that the bitter end of the two wire ropes remains stationary following a wire rope failure. If equalizer motion following a wire rope failure is permitted by the design of the hydraulic equalization system, Ederer Incorporated has determined that the angular, velocity of the equalizer will be approximately constant until it stops when it contacts a structural member. To be conservative, the maximum angular velocity, which is determined by the peak wire rope loading and the shock absorber design, is used in this analysis for the constant angular velocity. The total angle through which the equalizer may rotate is determined from the equalizer configuration. Therefore, the effective time period during which the equalizer rotate is determined by dividing this angle by the assumed average angular velocity.

p. Model of Failure

The failure is assumed to be a complete severing of one wire rope, with the attendant increase in static and dynamic tension in the remaining ropes and additional dynamic forces on the drum resulting from the load motion.

4. General Solution of the Equations of Motion That is Valid When the Drum and Equalizer are Rotating at Constant Rates

This solution is a more general solution than was developed in Section 7 of reference (a) for the stationary drum case, which is a special case of the more general case in which the drum is rotating at a constant rate. For the stationary drum case, reference (a) included viscous damping of the mechanical system. However, such damping is omitted from this more general case, in which the drum and equalizer may be in motion, for the same reasons that it was omitted in the rotating drum case of reference (a), i.e., because the weak damping appropriate to the crane system has only a small effect over the period of the very few oscillations encountered prior to the stopping of the drum and equalizer. Omission of damping is conservative and its inclusion would have unnecessarily complicated the solution of this more general case. The solution developed in Section 7 of reference (a) can be used when the drum and equalizer finally stop rotating to account for viscous damping for the remainder of the analysis.

The equation of motion of the load becomes:

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]a,c

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5. General Solution of the Equations of Motion that is Valid When the Drum is Being Retarded and the Equalizer is Rotating at a Constant Rate

This solution is a more general solution than was developed in Section 6 of reference (a) for the rotating drum case in which no ropes had failed and the equalizer is stationary. That solution is a special case of the more general case provided herein in which ropes have failed and the equalizer may be rotating at a constant rate.

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END OF LETTER