Open file - Jeffrey Mining

CONCEPT STUDY
SHUTTLE CAR CABLE REEL

Prepared for

**UNITED STATES DEPARTMENT
OF THE INTERIOR, BUREAU OF MINES**

By

**JEFFREY MINING MACHINERY DIVISION
DRESSER INDUSTRIES, INC.**

JEFFREY DRESSER

**PHASE I COMPLETION REPORT
CONTRACT NO. J0395012**

**SHUTTLE CAR CABLE REEL
IMPROVEMENT FEASIBILITY STUDY**

SUBMITTED APRIL 1980

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No.

4. Title and Subtitle SHUTTLE CAR CABLE REEL IMPROVEMENT FEASIBILITY STUDY	5. Report Date April 1980 6.
7. Author(s) R. J. GUNDERMAN	8. Performing Organization Rept. No. N/A
9. Performing Organization Name and Address Jeffrey Mining Machinery Division Dresser Industries, Inc. 274 E. First Avenue Columbus, Ohio 43216	10. Project/Task/Work Unit No. L-104008 11. Contract(C) or Grant(G) No. (C) JO 395012 (G)
12. Sponsoring Organization Name and Address Department of the Interior U. S. Bureau of Mines 4800 Forbes Avenue Pittsburgh, PA. 15213	13. Type of Report & Period Covered Phase I Completion Report 14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

Cable reel systems for shuttle cars were investigated to determine whether an improved system could be identified. Interviews and mine visits were conducted to better define limitations and problems with present systems. Although simple and relatively inexpensive, present cable reel systems are not fully satisfactory.

Several concepts for a different technical configuration were formulated and evaluated. An all ectric system using electronic control and external sensors was recommended for further development.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

Shuttle Cars
Cable Reels
Hydraulic Operated Cable Reels
Electric Operated Cable Reels

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) Unclassified	21. No. of Pages 74
	20. Security Class (This Page)	22. Price

(See ANSI–Z39.18) *See Instructions on Reverse* OPTIONAL FORM 272 (4–77)
(Formerly NTIS–35)
Department of Commerce

FOREWORD

This report was prepared by the Jeffrey Mining Machinery Division, Dresser Industries, Inc. under USBM Contract Number HO 387027. The contract was initiated under the Coal Mine Health and Safety Research Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Mr. George Conroy acting as the Technical Project Officer. Mr. Alan Bolton, Jr. was the Contract Administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period February 1979 to January 1980. This report was submitted by the author in April 1980.

John E. Trybuski and Associates, Inc. performed the study details and analyses under subcontract to the Jeffrey Mining Machinery Division. Major contributors included Laurence W. Crevoiserat and George Homa.

There are no claims for "Subject Inventions" resulting from this work.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION 1.0

INTRODUCTION

Shuttle cars are the most popular form of intermediate haulage in underground coal mines today. They carry the coal as it is cut from the face back to the panel belt or rail haulage loading point. These distances may typically be 500 feet, but often times may be as long as the trailing cable, which provides power to the vehicle, will allow. The haulage distance may be as great as 1000 feet if the cable tie-point is located mid-way in the route and the cable length exceeds 500 feet.

Other types of power for face haulage vehicles, such as battery or diesel engine, allow freedom from the trailing cable, which is a tremendous advantage in some mining applications. However, these other forms of power have limitations or are found unacceptable for various reasons. Thus, the shuttle car with the electric trailing cable is still the "work horse".

The cable reel system functions without any specific operator action. It is intended to wind up or pay out the cable in a smooth fashion without any sizable jerks, cable whip, lag or danger of being run over by the shuttle car or being pinched.

Unfortunately, the cable reel systems do not function as smoothly as intended. There are safety hazards due to cable whip or cable parting. Breaks or damage in the cable result in considerable downtime while a splice is being made. Splices and other cable deterioration require complete cable replacement sometimes after only a few months of operation. Maintenance is not always what it should be and the hydraulic systems may suffer problems from contamination. The present cable reel systems do have the distinct advantage of being relatively simple and inexpensive.

Phase I of this program, which is reported herein, addressed the question as to whether a better type cable reel system concept could be identified. In order to do this a detailed review and assessment of related activities was initiated. This included on-site inspection of the operation of shuttle cars in working mines, as well as the review of vendor descriptive literature and operating manuals for shuttle cars of manufacturers other than those observed. In addition, relevant published technical data was obtained and reviewed for unique developments in this field, including a "state-of-the-art" patent search for shuttle car cable reels and assessment of applicable patents resulting therefrom. Finally, a survey of parallel research efforts was completed and these activities were reviewed for possible applicability to this program.

This led to a detailed analysis of the cable reel system, its operating characteristics, operating deficiencies, and performance objectives.

Having identified system performance requirements, present deficiencies and reasons therefor, possible component and subsystem concepts were generated and screened. An evaluation technique was developed to identify the combined system concept(s) which appeared to best satisfy performance requirements.

Theoretical analyses of shuttle car and cable reel motions revealed that it is very difficult to fully satisfy normal cable reel wind and unwind requirements, particularly when passing the tie-point, without some external (to the cable reel) means of interim cable storage.

Concepts were formulated using many different ideas and/or combination of ideas. Some of these idea considerations are summarized in Table 1.1.

Remaining cable reel operating deficiencies were isolated and alternate improvement concepts were generated to replace unsatisfactory subsystems. The preliminary design of the resultant system was completed, illustrating system components, orientation and space requirements.

The shuttle car cable reel system concept ultimately developed minimized cable "whip" by approaching a uniform tension system. This concept also provides superior performance characteristics with anticipated lower maintenance requirements. Overall benefits of higher productivity and reduction of safety hazards are therefore obtained.

TABLE 1.1 SUMMARY OF CONCEPT CONSIDERATIONS

- IMPROVED CONTROL OF DRIVEN REEL (HIGH INERTIA)
    - HYDRAULIC
    - ELECTRIC
    - MECHANICAL
- NON-ROTATION CABLE BASKET (LOW INERTIA)
- TENSION SENSORS
- ANGLE SENSORS
- VEHICLE SENSORS
- MODULARIZE COMPONENTS
- SLACK TAKE-UP

The recommended improvement concept shown in Figure 1.1, varies significantly from present shuttle car cable reel systems. An electric motor drive replaces the hydraulically powered system. Electronic control of input to the high torque drive motor provides much faster reaction to the varying torque requirements on the cable reel. A cable tension controller automatically adjusts reel motion to compensate for several feedback signals which are indicative of shuttle car location and movement. A rugged, low-profile cable guide compensates for cable slack. Manual system adjustments are implemented by the shuttle car operator or a mechanic. The total system thus provides an essentially uniform tension to the cable, eliminating tension excursions and resultant cable whip.

Potential improvements over existing problem areas are listed in Table 1.2 along with that part of the concept offering the improvement.

The following section discusses the background investigation of difficulties experienced along with different technical approaches tried over many years time. Section 3.0 summarizes the analysis of requirements. Some of the concepts that were generated are identified in Section 4.0 and the final recommended concept is described in Section 5.0.

Further work to demonstrate feasibility is recommended. Equally important as the technical functions are the mine worthiness of the system hardware and the economic values. At least the electronic control of the electrically driven cable reel should be demonstrated to verify the fast reaction to rapidly varying torque requirements.

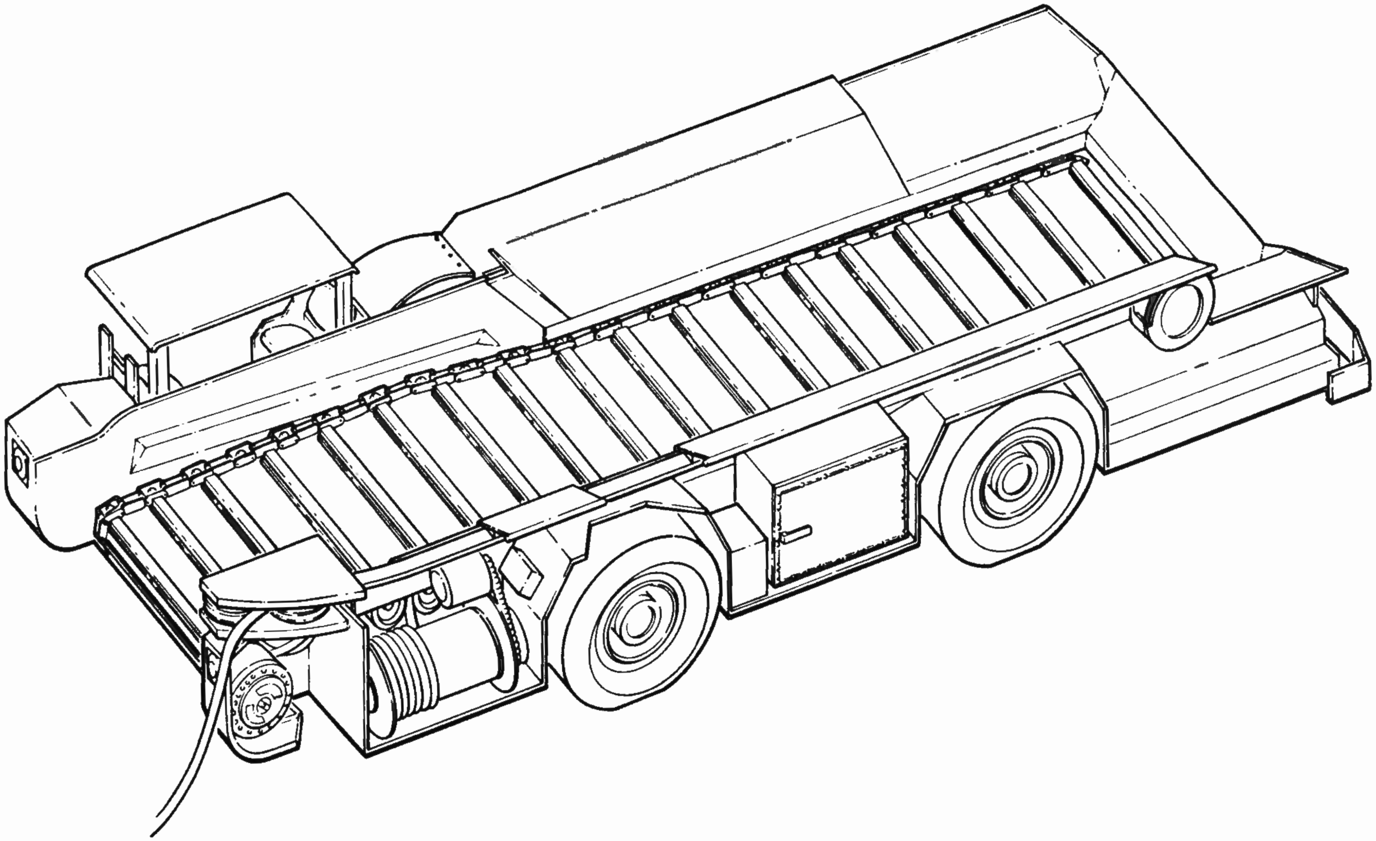


FIGURE 1.1 ARTIST SKETCH OF ELECTRIC DRIVE CABLE REEL SYSTEM ON SHUTTLE CAR

TABLE 1.2 LISTING OF POTENTIAL IMPROVEMENTS RESULTING FROM RECOMMENDED CONCEPT

CONCEPT APPROACH	PROBLEM AREA IMPROVED
- ELECTRIC DRIVE AND CONTROL	- HYDRAULIC CONTAMINATION
- ELECTRONIC CONTROL USING MULTIPLE SENSING/FEEDBACK LOOPS FOR FASTER RESPONSE IN CABLE REEL INERTIA	- CABLE WHIP
- TRAVERSING GUIDE ON SIDE OF SHUTTLE CAR	- CABLE RUN-OVER DURING BACKSPOOLING
- AUTOMATIC SHUTDOWN USING NON-CONTACTING SENSOR TO MEASURE CABLE LENGTH	- CABLE SEPARATION FROM REEL
- REPLACEABLE MODULES	- MAINTENANCE DIFFICULTY
- AUTOMATIC SHUTDOWN WHEN EXCESSIVE CABLE TENSION IS SENSED	- CABLE JAMMING (PARTING)

SECTION 2.0

BACKGROUND INVESTIGATION

Cable reel systems for shuttle cars have been essentially the same basic configuration for many years. The question was raised whether these systems are generally quite adequate for the purpose they serve or is there just a lack of knowledge on how to implement a better system. The continuing development efforts to improve the reel systems are evidence that a better system is needed but not yet identified. Appendix "A" lists references for much of the data used in this study.

2.1 PATENT AND LITERATURE SEARCH

Investigation of the present state-of-art discloses that all cable reel systems on mine type shuttle cars are hydraulic. That is, an hydraulic motor drives the reel and an hydraulic control valve senses the pressure level to switch between at least two different pressure relief settings. Cable reel systems on other type vehicles, such as rail locomotives and earth scrapers, are frequently electrical type systems. A patent search going back for fifty years was conducted for cable reels used on mining vehicles. These patents may be grouped into categories as shown in Table 2.1.

A summary description of each patent is provided in Appendix "B".

Many of the patents concern hydraulic systems. This is indicative of both a strong favoritism toward the hydraulic system and much effort to find a better way to control the hydraulic system. Because of these two factors most of the attention in this program was directed toward approaches other than hydraulic control. It would seem that the probability for a step improvement in an hydraulic control is relatively low since so much effort has already been directed that way.

This continued effort toward a better hydraulic control was also noted for techniques not presently covered by U. S. patents during discussions with firms, both U. S. and foreign.

TABLE 2.1 SUMMARY LISTING OF PATENTS BY CATEGORY

CATEGORY	NO. OF PATENTS
Electrically powered cable reels	3
Hydraulically powered cable reels	8
Control valves for hydraulic motor units for cable reels	5
Means for continuously maintaining tension on the cable wound on a cable reel	4
Guides to prevent the cable from becoming fouled when being reeled or unreeled from the cable reel	4
Miscellaneous apparatus related to cable reels	7

2.2 INTERVIEWS AND OBSERVATIONS

Visits to mines and discussions with mine operator personnel indicate that a pragmatic approach is generally adopted. When difficulties are experienced the maintenance personnel try to work out a solution. If the equipment is relatively new the equipment manufacturer may assist by making adjustments and/or exchanging components. Eventually, the mine operators arrive at a level of performance that they live with.

Some of the solutions to the hydraulic system involve nothing more than increasing the pressure setting on one or both relief valves until the cable pick up is acceptable. This may be done without instruments and may result in both pressure settings being very high. This causes higher tension on the cable and increased whip.

Other operators believe that clearances on hydraulic control valves are too tight for the oil contamination level. These valves are sometimes dismantled and the parts reworked to increase clearance. Pressure relief settings are then reset but the amount of care or precision in the whole process is unknown. Some claim they have no more difficulty after increasing the valve clearances.

More attention to maintenance techniques resolves some problems. This is especially true with regard adding make up oil to the shuttle car hydraulic tank.

Not all problems with the cable reel systems concern the hydraulic control and drive. Traveling beyond the cable length parts the cable. Re-entering the cable on the reel is generally awkward and time consuming. Problems too, are experienced with the reel support and bearings, with the level wind, and with the drive chain and sprocket. These latter items are mostly a matter of good mechanical design.

2.3 PROBLEM DESCRIPTION

When questioned thoroughly about existing cable reel systems on shuttle cars, the mine operators concensus says a better system is needed. The undesirable effects are there. The cable

- has excessive whip as the vehicle stops,

- has excessive lag in windup after vehicle start,
- may be run over in backspooling,
- may be separated because of too much tension,
- is not long enough,
- requires splicing too frequently, and
- has too short a life.

Some causes for these effects are listed in Table 1.2 along with a technical approach for improvement. One significantly different approach to the system is noted in Table 1.1; namely, a non-rotating basket or box into which the cable is stuffed. This approach was given serious consideration because it avoids the large and varying interia of the spinning reel. Another significant advantage to a non-rotating basket is elimination of expensive slip rings for electrical connection.

Some experimentation has been tried by others with the non-rotating cable basket on a conventional shuttle car. This work was abandoned when it was learned that some form of organizing the lay of the cable within the box is necessary to avoid tangling and that the cable undergoes significant twisting.

Another more recent device of this type lays the cable into a vertical basket via a rotating feed tube. A conical center section in the basket keeps the cable organized as it comes out of the rotating feed tube and falls to the bottom of the basket.

Attempts to identify a concept for the shuttle car using the non-rotating basket approach were unsuccessful. The space factor is too restrictive, especially when the width or diameter must not exceed 24 inches. Also, cable twist is a problem.

Cable reel systems frequently use external sensors in applications other than coal mining. It would seem that any improvement over existing shuttle car applications will require additional sensors beyond sensing the hydraulic fluid pressure (or electrical current as an analogy). Successful application will require making external sensors mine worthy.

The maintenance of a uniform low cable tension - a specific, unvarying value regardless of reel rotation and shuttle car movement - would theoretically eliminate cable whip and its detrimental effects and would thus minimize personal safety hazards as well as shuttle car downtime, resulting in higher productivity. In order to obtain such a uniform cable tension, all potential causes of tension variations must be examined.

Analysis of system requirements is discussed in the following section. Section 4.0 describes a number of concepts and the evaluation which led to the concept recommended in Section 5.0.

SECTION 3.0

ANALYSIS OF REQUIREMENTS

In assessing the potential benefits of the Shuttle Car Cable Reel Improvement Study, it became obvious that multiple system performance advantages should be considered. Thus, cable reel system improvement was not limited to merely correcting present operating deficiencies. A total advancement of system performance capabilities - speed, reliability, and versatility in excess of that of present shuttle cars - became the goal. This was reflected in the initial guidance by the Bureau of Mines as presented in its tentative performance specifications for the cable reel system.

3.1 PERFORMANCE SPECIFICATIONS

A thorough review of these suggested specifications, as well as the Bureau's guidance for subsequent performance evaluation testing of new hardware, provided the design objectives for a satisfactory shuttle car cable reel system. As a result of this review, a few changes to the tentative specifications are suggested. Some shuttle cars are capable of accelerating faster than 1.36 miles per hour per second (2 feet per second per second). The maximum speed allowed by the Code of Federal Regulations (6 mph) can be reached in less than 3 seconds and acceleration rates within one gear range may be even much faster. Therefore, a maximum straight line acceleration from standstill of 3 feet per second per second is recommended.

Section 18.45 of the Code of Federal Regulations (CFR) allows a top vehicle speed of only 6 miles per hour. Therefore, the "crash stops" requirement should only be from 6 rather than 8 miles per hour.

A more important requirement is reel acceleration on turns. The equivalent cable accelerations and velocities passing through the level wind when the shuttle car is going around 90 degree turns at 6 mph are 10.5 feet per second per second and 9 feet per second when the reel is on the inside radius during the turn, and 6 feet per second per second and 12 feet per second when the reel is on the outside radius during the turn. These values were arrived at through graphical analysis. Therefore, a new requirement for this condition is included in the tentative specifications.

Maximum cable length is limited by the CFR as a function of cable size. Generally this will be less than 750 feet. However, it is recognized that splices add to the layering build-up and some extra capacity should be allowed. Also, if shielded cable should be required at some future time then the reel size should be adequate if designed for 750 feet of conventional trailing cable. Consequently, an added requirement for cable storage capacity is suggested.

The tentative specifications with the recommended changes are provided in Appendix "C". However, the analysis in this section used values in the original tentative specifications that were supplied with the request for proposal.

If these tentative specifications can be attained then the new cable reel system will have a number of advantages over the existing systems. These include:

- Less vehicle downtime for cable repair
- Cable whip minimized or eliminated
- Cable slack (excessive) minimized so that it is not run over or pinched
- Minimize or eliminate problems of hydraulic fluid contamination
- Assure improved maintenance capability
- Added reel capacity for longer cables or possibly shielded trailing cables

As concepts were developed and evaluated these specifications served as a guide. Some concepts may offer additional advantages and, if adopted, some more specific requirements might be added to the specifications.

3.2 OPERATING CHARACTERISTICS

Existing shuttle car and cable reel operations do not approach the design objective and, at best, can be described as troublesome. Many of these problems seem to be operation-or maintenance-related. The causes of system malfunctions - and potential hazardous conditions - may be poor quality hydraulic components, improper adjustments of the hydraulic system, contaminated hydraulic fluid, cable hang-up due to accumulation of dirt or to poor splices, and overrun of the vehicle when cable is completely payed out.

Even when a conscientious underground maintenance program is maintained, inherent physical characteristics of the cable reel system and the effects of the underground environment may result in operating problems, safety hazards, and general deterioration of performance below the design objective. Operating deficiencies and problems which appear to be common to most shuttle car cable reel systems include the following:

- Severe cable tension transients in passing the cable tie-point.
- Potential runover of the cable during back-spooling.
- Incorrect cable reel hydraulic pressure resulting from:
    - Improper valve settings. Present hydraulic systems for cable reels operate at two discrete pressure levels.
    - Changes due to contamination. Present control valve design incorporates close mechanical tolerances which make the valves more sensitive to contamination.
- Pulling the cable apart, which may be caused by many operational malpractices, such as:

Improper or inefficient cable splices resulting in reduced flexure and curling at splice edges.

Abrasion of the cable, particularly when it comes in contact continually with locations on the shuttle car and with vertical mine ribs at corner turns.

Overrun of the shuttle car (cable reel) at the end of the cable length, tending to strip the cable from the reel.

- Cable jerks in altering reel motions because of improper hydraulic system response time and reel inertia.
- Cable hang-up on the cable reel because of the accumulation of dirt, mud, or coal or because of an improper cable splice.

3.3 FUNCTIONAL REQUIREMENTS

Consideration of the objective performance specifications and a thorough review of current operating limitations led to the determination of the various functional requirements of a cable reel system satisfying the improvement specification. These necessary functions are shown in Figure 3.1, along with the illustration of those functions performed by present cable handling systems.

This functional diagram indicates the many operational steps not accomplished by existing cable reel systems, illustrating the reasons that current cable handling techniques are incapable of providing the desired level of performance.

3.4 CABLE REEL ANALYSIS

3.4.1 Constant Cable Tension

Although the Functional Block Diagram (Figure 3.1) indicates numerous functional deficiencies of the present system it appears that the most

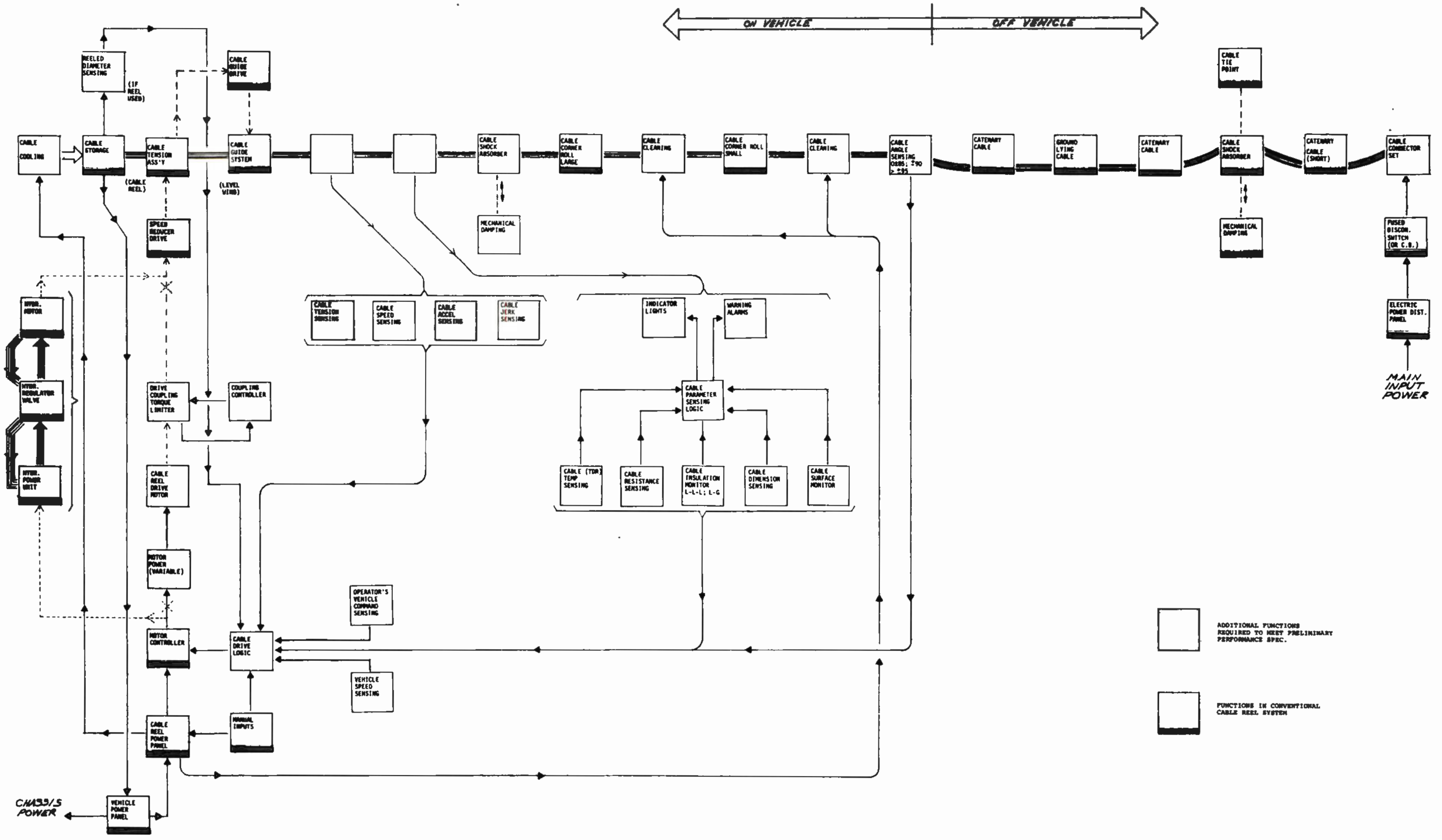


FIGURE 3.1 CABLE HANDLING - FUNCTIONAL BLOCK DIAGRAM

obvious problem - excessive or inadequate cable tension - would be solved by the maintenance of a truly constant cable tension at all times. Similiarly, if such a constant cable tension could be maintained under all conditions of shuttle car motion and rest, a low tension value would imply a low stress in the cable and included splices.

There are a number of complications which must be considered, however, in a constant, low tension cable reel system.

- An extremely low cable tension will result in an immediate drop or sag of the cable as it leaves the shuttle car, increasing the danger of running over the cable.

- In order to reduce the danger of possible runover, the minimum catenary length[1] must be equal to the length of the shuttle car to allow for backspooling.

- For a cable catenary length of 30 feet (approximate length of a shuttle car), a constant tension of approximately 350 pounds would be required. The effect of cable tension on catenary length is shown in Figure 3.2.

- Meanwhile, excessive heat would be generated at standstill when the shuttle car idles if 350 pounds tension is required.

Thus, a constant tension system as defined would exceed the design cable tension specification of 100-300 pounds, resulting in excessive stress loadings in the cable.

---

[1] It was assumed in all analyses that cable sag shape is that of one-half of a theoretical catenary. For convenience, the horizontal distance from cable support to ground tangent is referred to as catenary length and the vertical distance from cable support to the ground as cable sag.

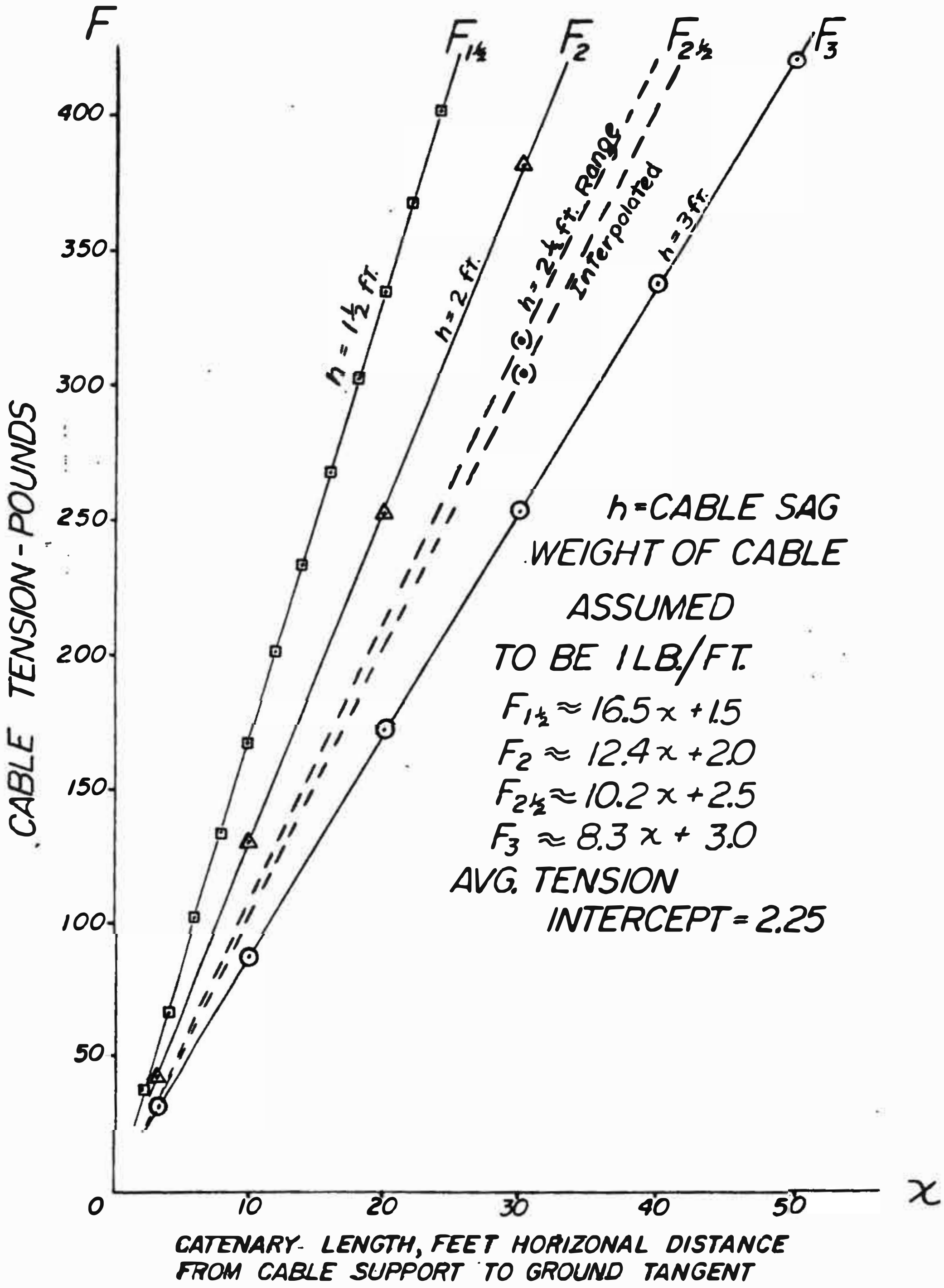


FIGURE 3.2 CATENARY CABLE TENSION

An analysis of Figure 3.2 illustrates an important point. In approaching the tie-point (within 30 feet of the cable reel), less tension is required to maintain the necessary catenary length, which at this point is equal only to the distance to the tie-point. This fact is useful in subsequent concepts for reversing reel rotational direction at the tie-point.

3.4.2 Cable Motion Analysis

In order to assess the impact of normal mine operations and necessary shuttle car movement upon the cable and cable reel, an initial analysis of shuttle car motion was completed. It was intended to isolate the various car motions and their subsequent impact on the cable and reel when the shuttle car accelerates, decelerates, reverses, and passes the tie-point from either direction. A graphic presentation of car location, velocity, and acceleration is presented in Figure 3.3, Motion Diagram - Shuttle Car, for the various excitations tabulated in Table 3.1. In this motion analysis shuttle car acceleration (a_v) is assumed to be a constant value of 3 feet per second per second during a specific time interval and maximum car velocity (v_v) is ± 12 fps, as defined in the specification before the suggested changes (CFR limits velocity to 6 mph).

Having graphically defined the various shuttle car motions, an analysis of the resultant cable and cable reel motion occurring concurrently was completed. These are superimposed on the Shuttle Car Motion Diagram as Figure 3.4, Motion Diagram - Shuttle Car and Cable Reel. Here again, it was convenient to make several assumptions which simplified the calculations, but did not affect the validity of results. Cable pay out elevation is assumed to be three feet above the floor level and the reeled cable radius is assumed to be a constant value

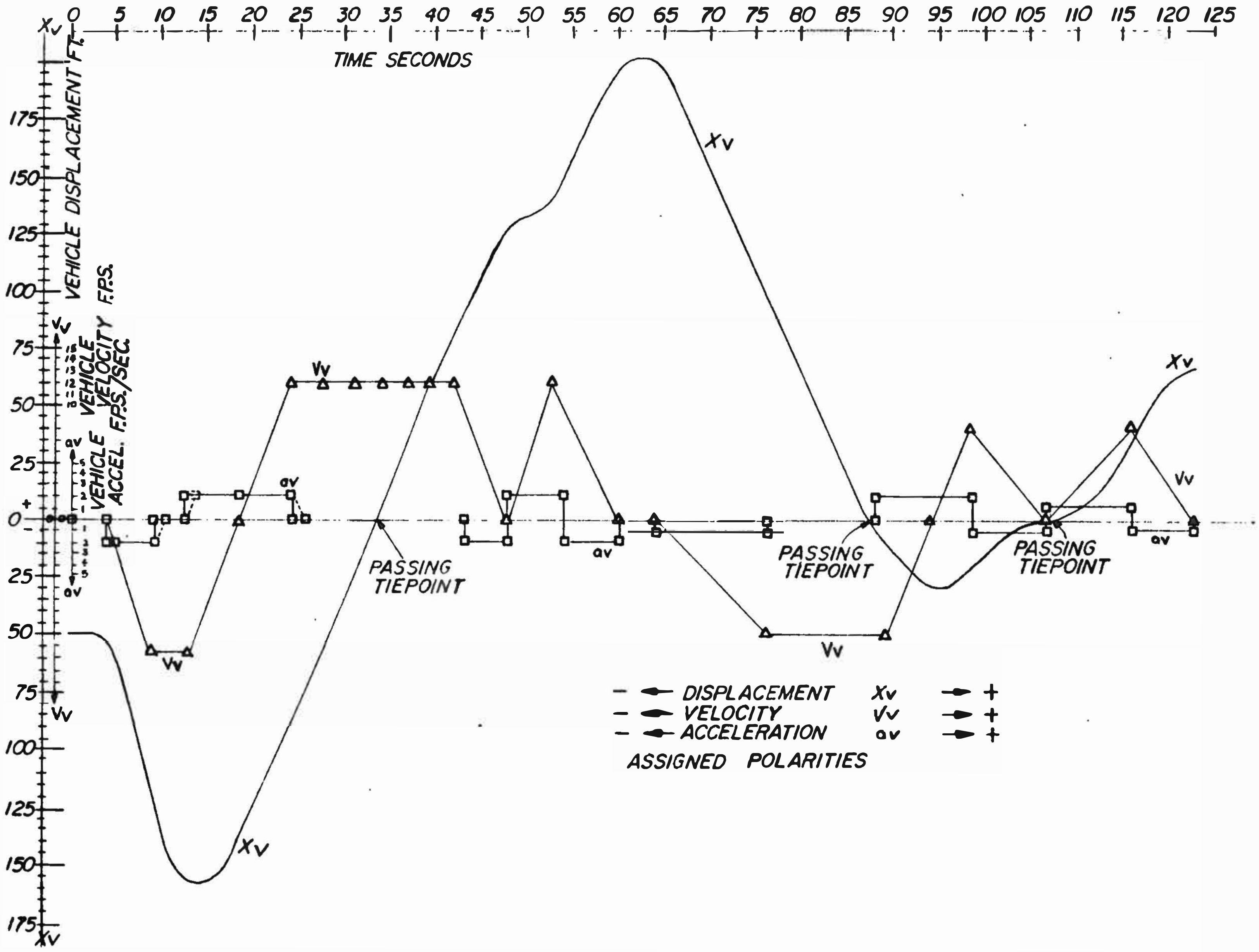


FIGURE 3.3 SHUTTLE CAR MOTION DIAGRAM

TABLE 3.1 SHUTTLE CAR MOTION SEQUENCE

Time Span Seconds		Shuttle Car Motion
From	To	
0	4	Stationary, 50 feet from tie point, front spooled.
4	10	Acceleration away from tie point at 2 fps^2.
10	13	Continue travel away from tie point at constant velocity.
13	19	Decelerate while traveling away from tie point.
	19	Reversal of direction of travel without idle time.
19	25	Accelerate toward tie point.
25	43	Travel at constant velocity, passing tie point from front-spooled to back-spooled.
43	49	Decelerate while traveling away from tie point to a momentary stop.
49	55	Accelerate in the same direction.
55	61	Decelerate in same direction of travel to stop.
61	64	Idle.
64	76	Accelerate back toward tie point at 1 fps^2.
76	88	Travel at constant velocity, passing the tie point from back-spooled to front-spooled.
88	94	Decelerate while traveling away from tie point at -2 fps^2.
	94	Reversal of direction of travel without idle time.
94	98	Accelerate back toward tie point at 2 fps^2.
98	106.5	Decelerate to near zero speed at tie point at 16/17 fps^2.
106.5	115	Accelerate in same direction, passing tie point at 16/17 fps^2.
115	123.5	Decelerate at 16/17 fps^2 to remote stop.

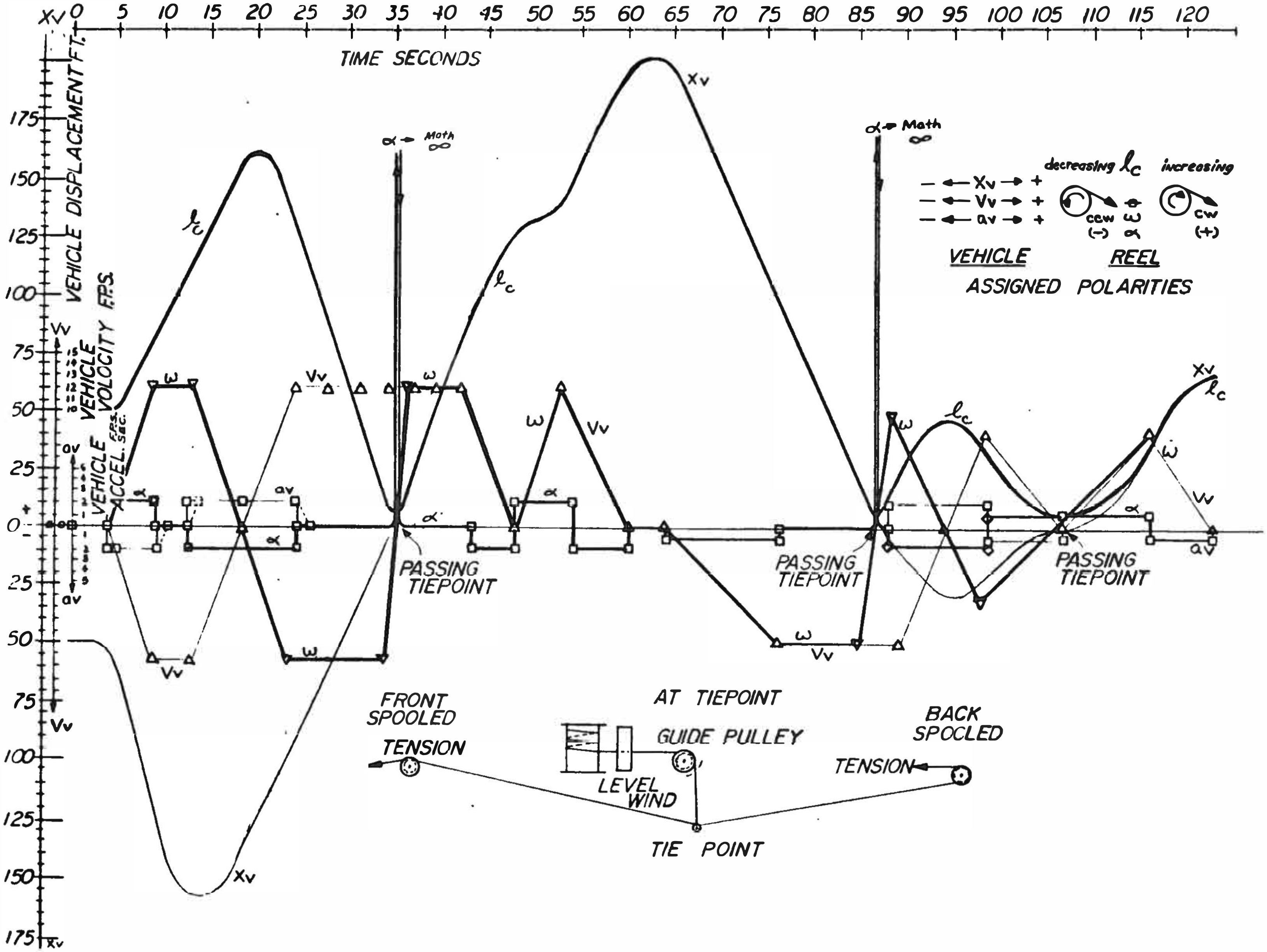


FIGURE 3.4 SHUTTLE CAR AND CABLE REEL MOTION DIAGRAM

of 12 inches, even though the actual radius varies as cable is picked up and payed out during working operations. (Inertia and torque vary substantially with reel radius.)

Ideally, cable linear velocity relative to the floor is always zero. The cable is picked up and wrapped around the reel during take up and is unwrapped and placed on the floor during pay out because of vehicle motion relative to the floor.

Review of the motion diagram in Figure 3.4 reveals a most significant problem involved in correcting cable whip. Extremely high levels of acceleration torque must be applied to the cable reel as the car passes the tie-point. The normal acceleration time of the cable reel from rest to maximum rotational speed ($\pm\omega$), defined as the rotational speed of the cable reel when the shuttle car is traveling at its maximum velocity of ± 12 fps, is six seconds. When passing the tie-point at the maximum speed of 12 fps, the cable reel must be reversed from $-\omega$ to $+\omega$ in approximately 1¼ seconds. In addition, this reversal occurs under the most severe condition of reel inertia. At the tie-point the reel is loaded with the maximum mass of cable, causing maximum inertia-induced cable tension variations.

It is also noted that a constant tension system, set at that tension value necessary to maintain the longest working catenary length, will aggravate the tie-point crossing. The plots of both cable length (ℓ_c) and reel acceleration (α) vs. time will be more severe and the transient torque required to reverse the reel will increase.

3.4.3 Cable Guide Analysis

In an attempt to minimize the possibility of the shuttle car running over the cable while approaching the tie-point, the installation of a cable guide along the car length was considered. Such a device would direct the cable from the cable reel along the guide, permitting its release from the car (beginning of cable catenary sag) from the end closest to the tie-point. This would greatly reduce the required catenary length and thus the cable tension. From Figure 3.2, a cable tension of 150 pounds would be more than adequate. Likewise, a lower reel torque will reduce the time required to accelerate the reel to maximum rotational speed or to reverse its rotational speed.

An analysis of possible cable guide motion was undertaken to determine the feasibility of a powered cable guide and a sequence of operation. The preliminary model was based on the maintenance of a constant cable length as the car passed the tie-point (say, 20 feet) and the motion of the guide providing all that was needed to maintain the cable tension. Initially, no provision was made in the model to limit the velocity of the guide or to assure it was decelerated to zero at the extremes of its travel. As a result, the guide was observed to impact the end of its track at the end of travel. Extension of the analysis to overcome these deficiencies indicates that such a powered guide system would require an extremely complex drive system

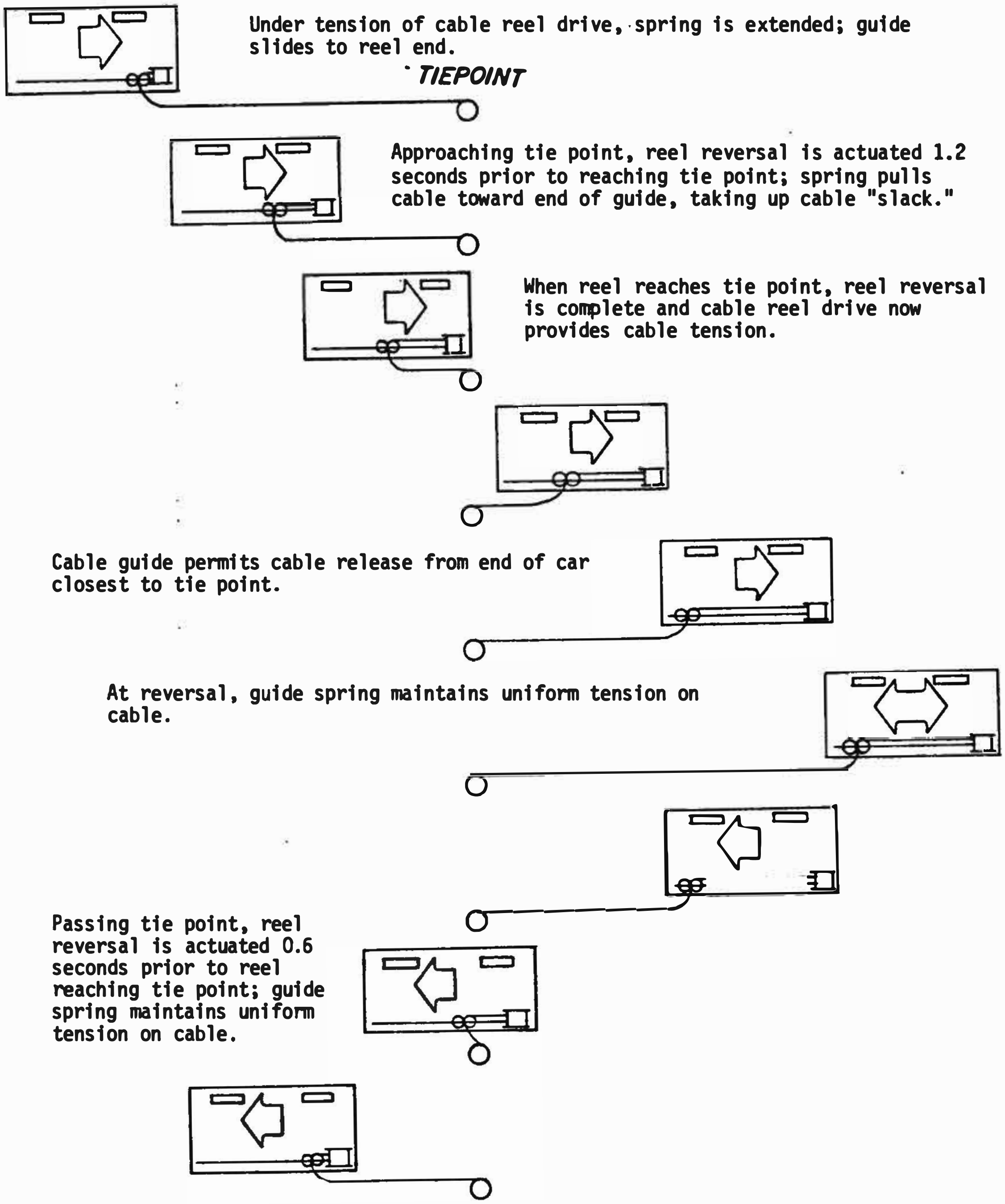
Because of the obvious benefits of such a cable guide system, preliminary analysis of an unpowered system was conducted. In this case, however, the operation of the cable guide was considered in conjunction with the cable reel drive rather than alone, as above. It was determined that a "hose reel" type of spring mechanism operating from the "far" end of the guide track, that is, the end away from the cable reel, can provide the force necessary to maintain a desired cable tension during cable reel "slack". For proper traversing of the cable, a spring tension of slightly less than the constant reel tension is required. This permits control of the cable from the cable reel except when the reel drive is in the process of decelerating.

The cable reel drive motor is designed to satisfy the reversal of cable reel rotation in the previously defined time period of 1.2 seconds without external assistance of any kind. Therefore, the function of the cable guide is merely to maintain the standard cable tension during drive motor deceleration, reversal, and acceleration. In so doing, the cable guide accumulates a small amount of cable. For example, if the shuttle car were passing the tie-point at a maximum speed of 8 mph (approximately 12 fps), less than 14.5 feet of cable must be controlled or accumulated.

As stated, the cable guide maintains this uniform tension as well as permitting release of the cable from the car end closest to the tie-point. Motion of the guide and reel is illustrated simply in Figure 3.5, Cable Guide Motion. In approaching the tie-point from the reel end of the shuttle car, reel reversal is actuated 1.2 seconds prior to the reel reaching the tie-point, permitting cable take-up by the cable guide until cable tension/control is again assumed by the reel drive motor at the tie-point. When approaching the tie-point from the opposite direction (guide end of car), reel reversal is actuated 0.6 seconds prior to the reel reaching the tie-point, so that the cable is controlled by the cable quide as the car crosses the tie-point (for approximately 7½ feet on each side of the tie-point).

The preceding analyses have been based upon the specifications originally provided by the Bureau and upon straight line motion. Reducing the velocity limit to 6 mph eases the requirements but when shuttle car turns are considered, the reel accelerations are even more severe.

Figure 3.6 is plot of cable velocity as it passes through the level wind. It was derived through graphical analysis



Under tension of cable reel drive, spring is extended; guide slides to reel end.

Approaching tie point, reel reversal is actuated 1.2 seconds prior to reaching tie point; spring pulls cable toward end of guide, taking up cable "slack."

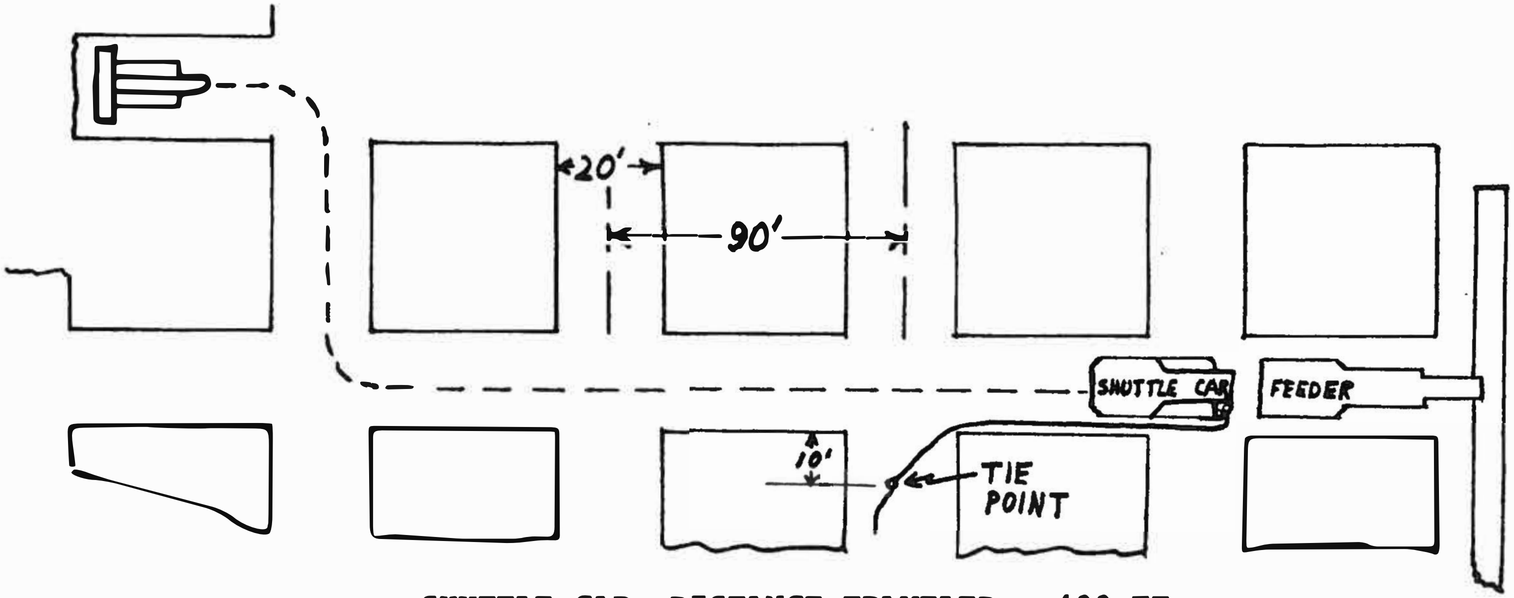
When reel reaches tie point, reel reversal is complete and cable reel drive now provides cable tension.

Cable guide permits cable release from end of car closest to tie point.

At reversal, guide spring maintains uniform tension on cable.

Passing tie point, reel reversal is actuated 0.6 seconds prior to reel reaching tie point; guide spring maintains uniform tension on cable.

FIGURE 3.5 CABLE GUIDE MOTION



SHUTTLE CAR: DISTANCE TRAVELED = 400 FT.
VELOCITY = 6 MPH

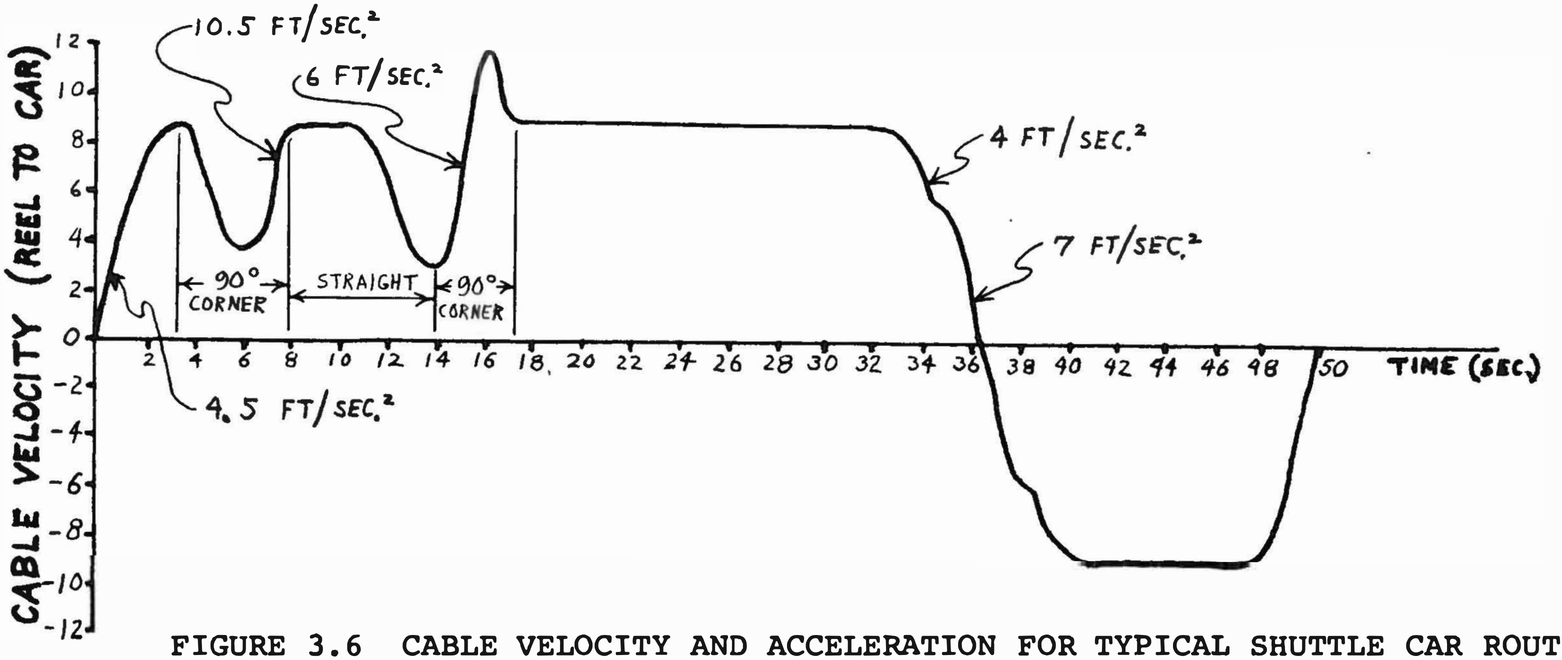


FIGURE 3.6 CABLE VELOCITY AND ACCELERATION FOR TYPICAL SHUTTLE CAR ROUTE

of an actual shuttle car operation during production. Maximum speed (6 mph) was maintained through the turns whenever possible. As noted, cable acceleration (through the level wind) can be at least 10.5 feet per second per second.

With these requirements in mind a number of system concepts were defined and evaluated. These are discussed in the following section.

SECTION 4.0

CONCEPT GENERATION AND EVALUATION

Initial concept generation was directed randomly to each functional component of the cable reel system identified in Figure 3.1. Possible methods of accomplishing each function or improvements to an existing method were listed without regard for necessary system interfaces and considering only the objective performance specifications. Essentially, this permitted the unconstrained identification of potential improvement concepts which could affect the cable reel system in any way. Many of these component and subsystem concepts are compiled in Appendix D, Component and Subsystem Concepts.

4.1 COMPONENT AND SUBSYSTEM CONSIDERATION

Ideally, the cable tension should be maintained at a constant value. In order to accomplish this, cable tension should be continuously monitored and a closed loop control system, properly damped, should be provided to the cable reel drive subsystem. In addition, the control system should be able to "forecast" reel motion variations before changes in motion occur.

A tabulation of cable handling methods including concepts to accomplish the various cable physical property requirements is presented in Figure 4.1, Cable Handling Concepts.

4.2 SYSTEM CONCEPTS

Each of the component concepts was reviewed to assess its feasibility for the intended functions, ability to interface with other system functional components, and probable complexity in the system. After this initial screening, a group of total system concepts was generated by assembling various component concepts. This resulted in five total system concepts for cable reel improvement.

In order to evaluate the physical arrangement of these five system concepts, they were proposed as retrofits to a conventional shuttle car. In one such shuttle car layout, the hydraulic system is located between the car wheels on the side opposite the operator's compartment.

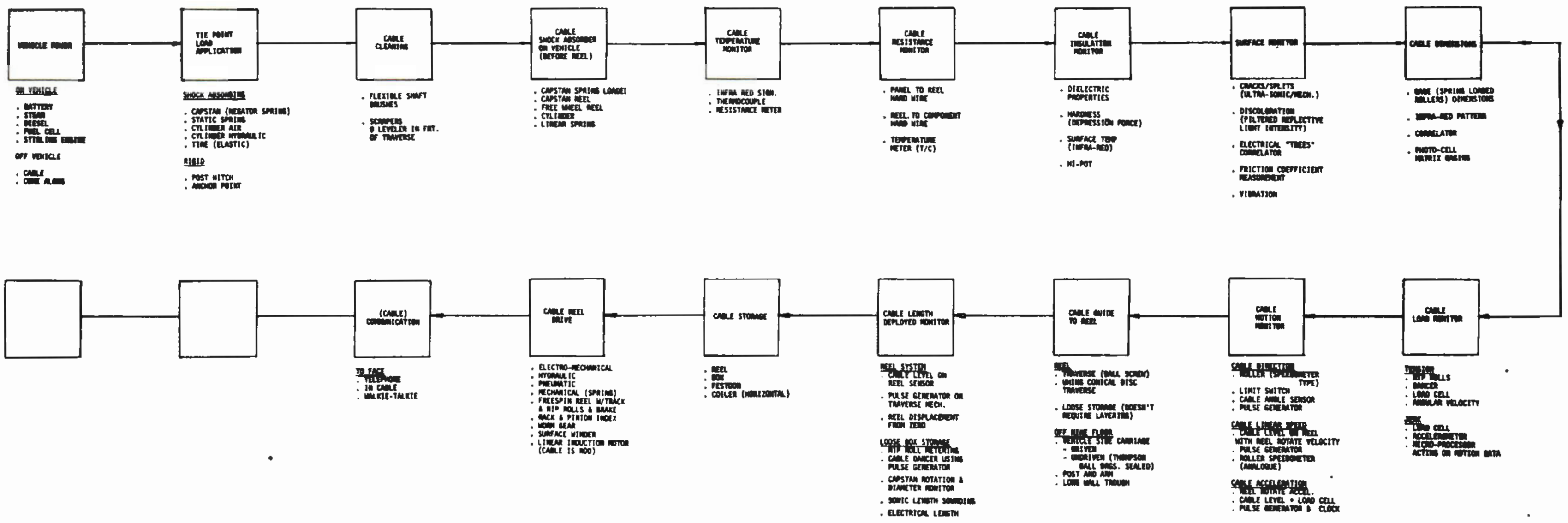


FIGURE 4.1 CABLE HANDLING CONCEPTS

An hydraulic valve is located on the same side of the vehicle as the power supply unit, in the wheel well, but out of the way of the vehicle wheel and tire assembly even when turning. The cable reel compartment is opposite the operator's compartment in front of the front wheel. The reel, with spooling mechanism, is located in the reel well with a metal cover overhead to prevent fouling or clogging of the spool mechanism and the reel.

These system concepts are illustrated on the typical shuttle car in Figures 4.2 through 4.6. A brief description of each follows.

4.2.1 Capstan Cable Drive from a Tractive Wheel

An hydraulic capstan (windlass) is added before the reel and spooling mechanism to provide a constant tension in the cable (independent of the layering radius on the reel). The capstan is driven from the tractive wheel shaft through a sprocket-chain combination. Drive is taken from the shaft to avoid drive train control problems when the car wheels are turning.

A free-floating, "balloon"-tired wheel mounted at the centerline of the shuttle car acts as a sensor for actual shuttle car speed. (Ideally, the wheel should be at the point where the cable leaves the car and be free to swivel.) This signal adjusts the reel hydraulic drive from the capstan, thus adjusting cable wind up or pay out speed. Adjustment is through a torque limiter.

The cable passes through a sliding cleaning device comprised of electrically-powered, counter-rotating flexible brushes.

An auxiliary takeup and cable guide (traversing guide) is mounted on the top of the shuttle car and parallel with its side. As the tie-point is approached, the guide accumulates cable along the full length of the vehicle from the cable reel. This accumulation of cable provides time for the reel drive to reverse, preventing cable runover by the car and reducing cable whip.

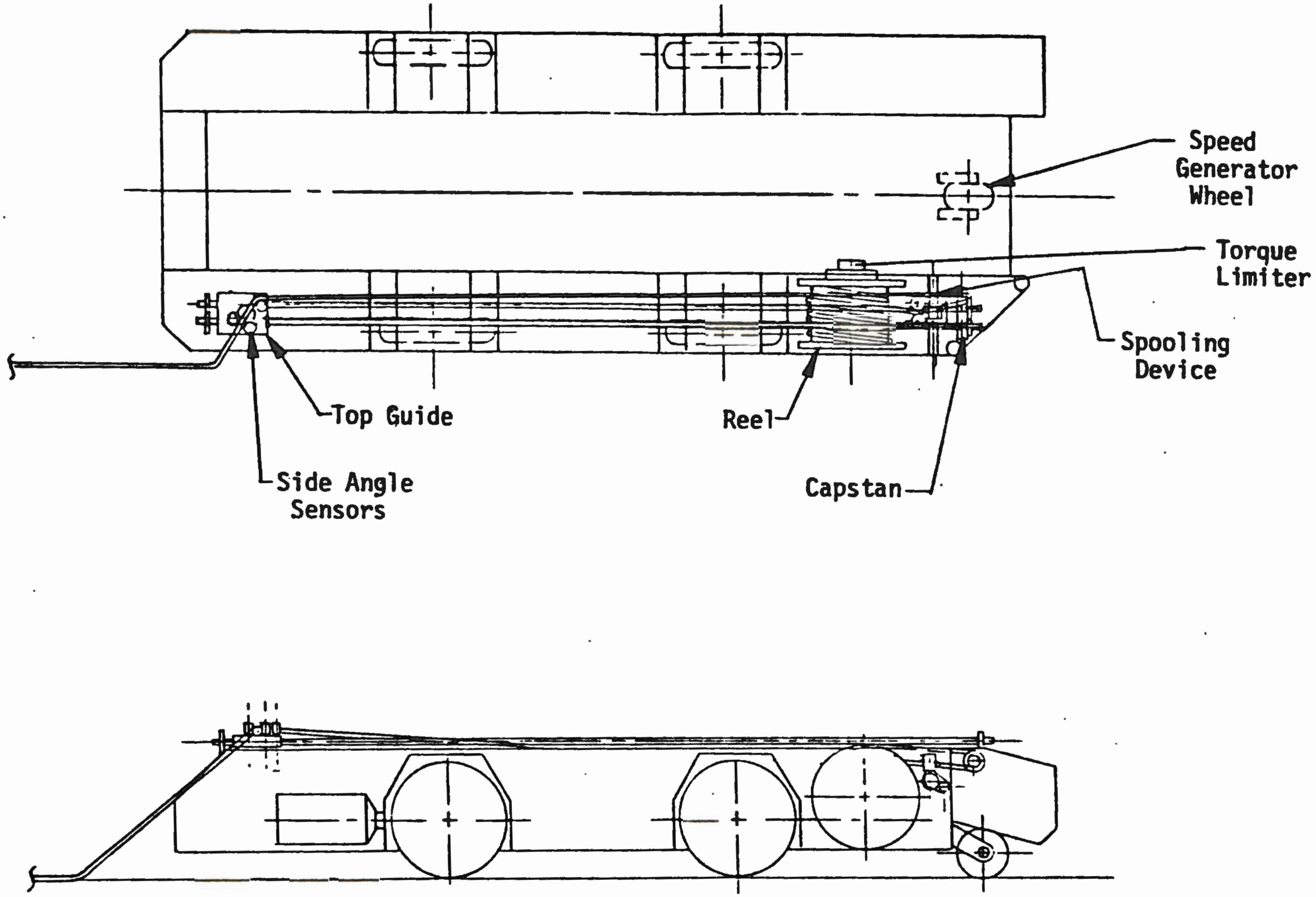


FIGURE 4.2 SYSTEM CONCEPT NO. 1 - CAPSTAN CABLE DRIVE FROM A TRACTIVE WHEEL

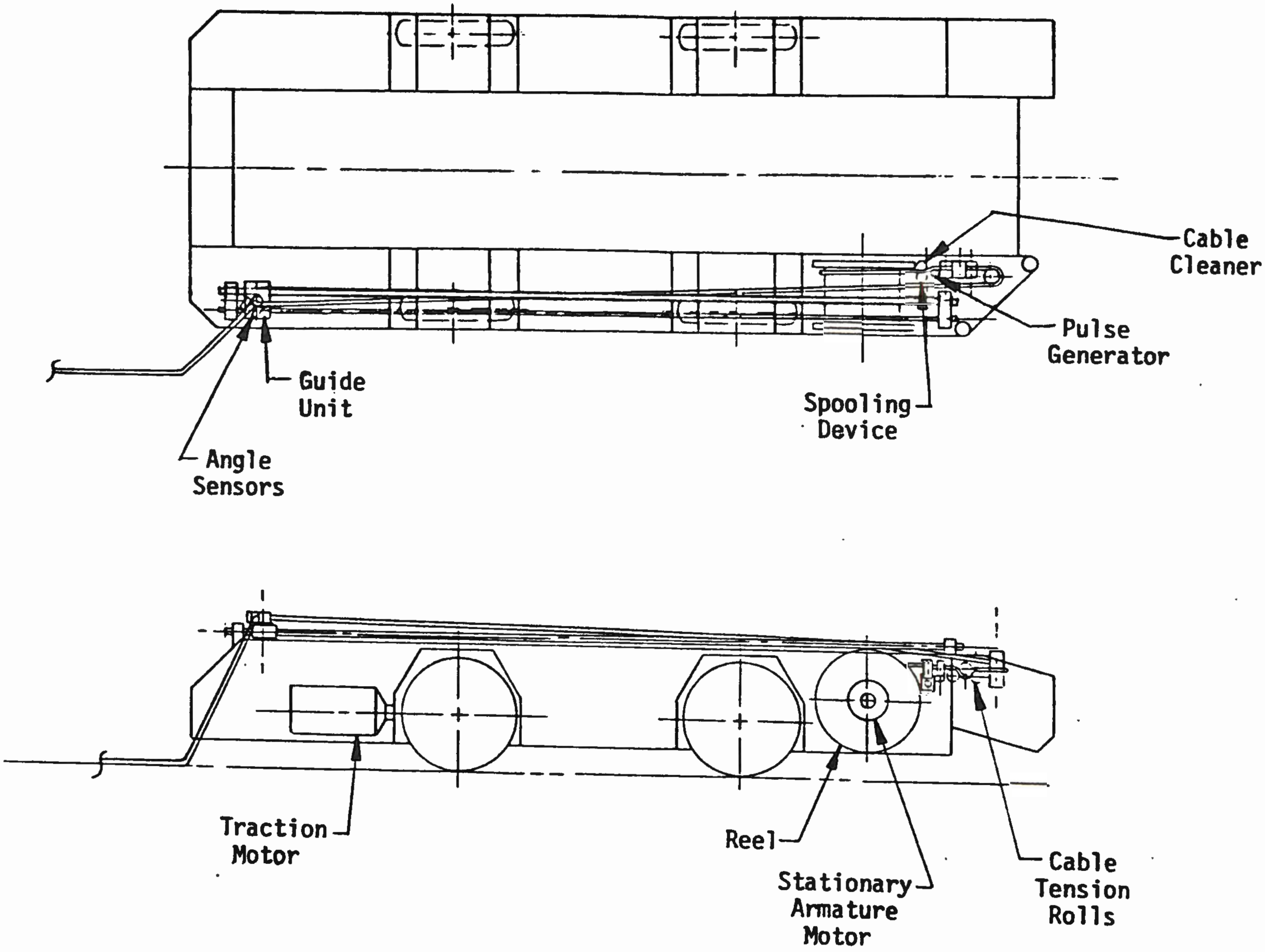


FIGURE 4.3 SYSTEM CONCEPT NO. 2 - INSIDE-OUT CABLE REEL DRIVE MOTOR

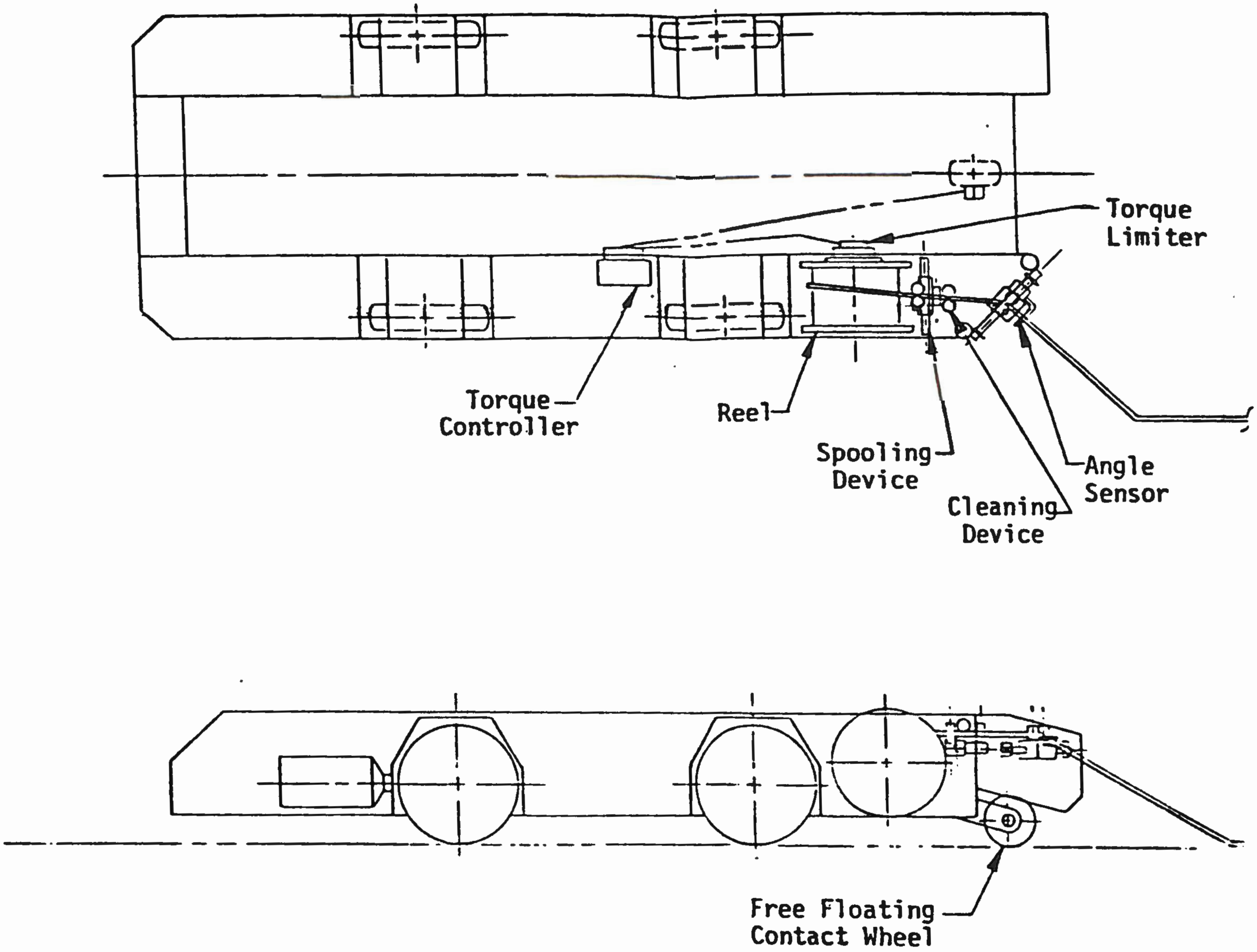


FIGURE 4.4 SYSTEM CONCEPT NO. 3 - REEL LOGIC SYSTEM

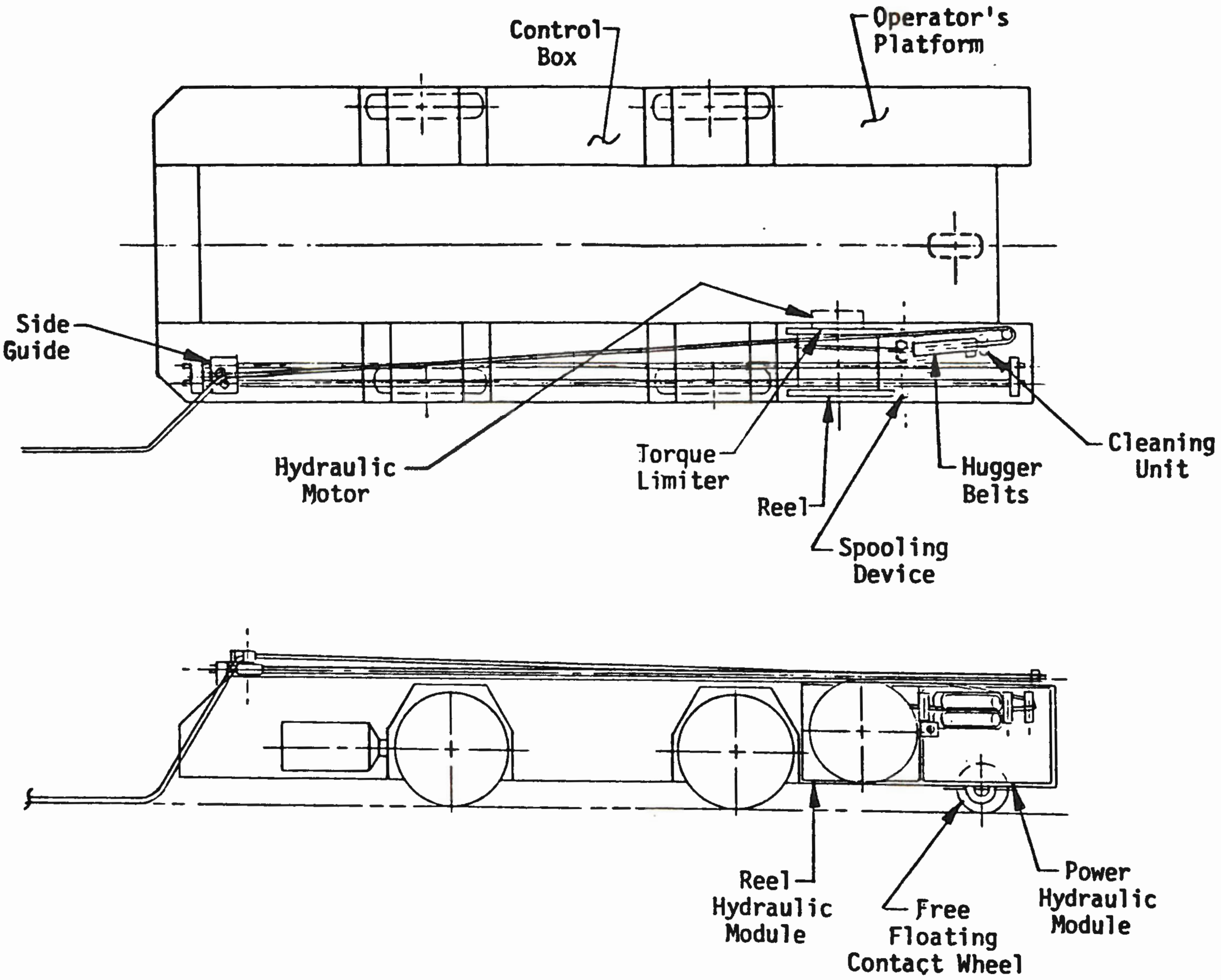


FIGURE 4.5 SYSTEM CONCEPT NO. 4 - MODULAR HYDRAULIC SYSTEM

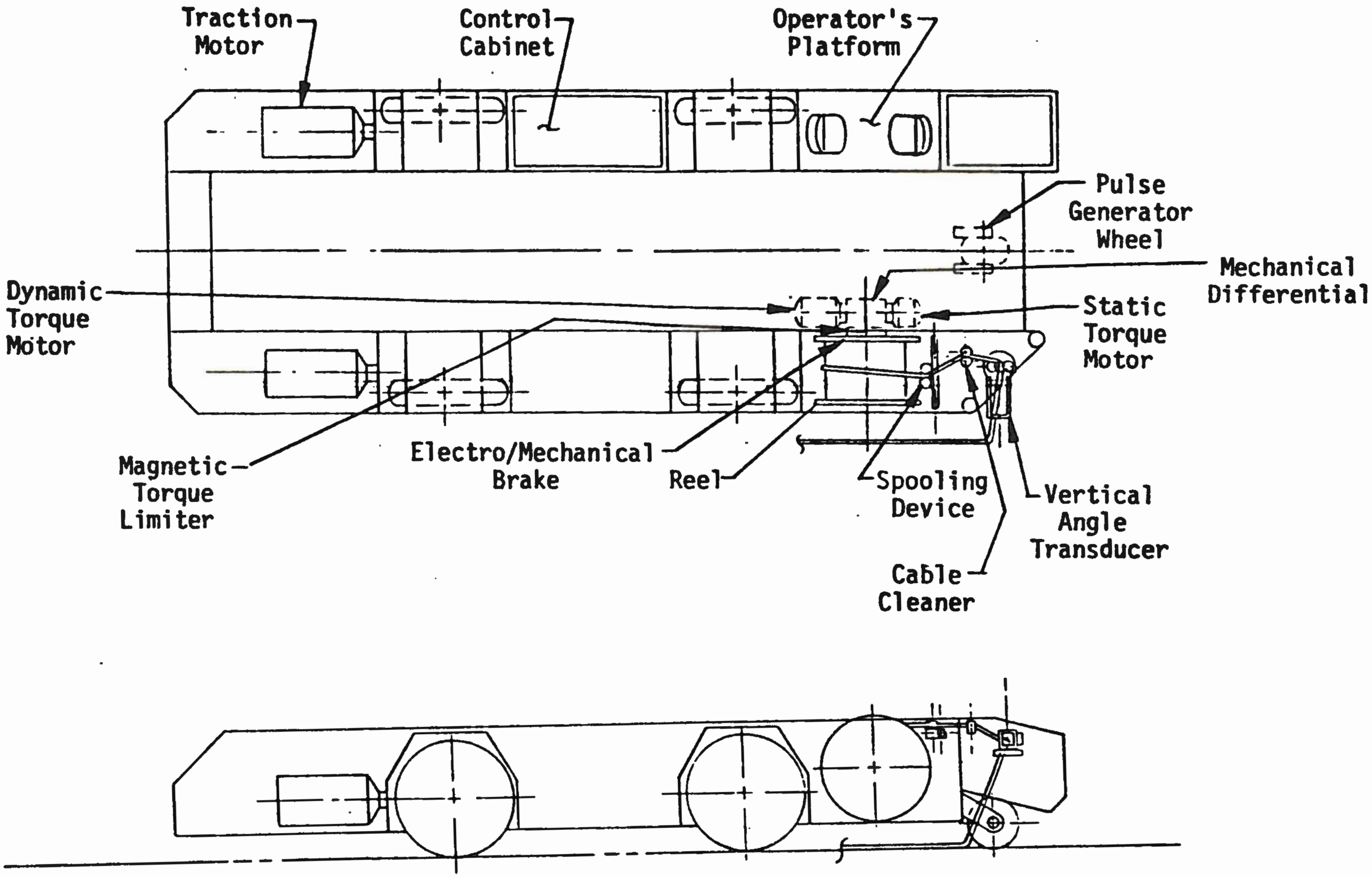


FIGURE 4.6 SYSTEM CONCEPT NO. 5 - ALL-ELECTRIC SYSTEM

The top guide (traversing guide) has a side angle sensor wand that straddles the cable during operation and indicates when the reel and capstan drive should reverse direction when approaching the tie-point. Vertical cable angle, which defines cable tension, is also measured by use of a wand on the top guide. The vertical angle sensor, like the free-floating wheel, adjusts the speed of the reel itself.

4.2.2 Inside-Out Cable Reel Drive Motor

An inside-out electric motor is used to drive the cable reel. The electric motor center (armature) is held rigidly, while the outer motor housing (field coils) rotate about the center. The outer housing acts as the cable reel core (inside diameter of spool).

In front of the reel and spooling mechanism is a triple roll tension sensing device (tensiometer), similar in form to a wire straightening device, in which a load cell is used to measure tension in the cable. A signal from the load cell will adjust the reel speed to correct for tension variations from the desired value. In front of the tension sensor is a cable cleaning device, consisting of flexible-shaft driven, flexible brushes.

A cable guide unit (as in Concept No. 1) prevents the car from running over its own cable. Side angle sensors straddle the cable as it leaves the top guide. Change in cable angle is sensed approaching the tie-point, signaling the reversal of cable reel motion.

A pulse generator is used to measure deployed cable length and to actuate automatic stopping of the shuttle car before the cable is totally unwound.

4.2.3 Reel Logic System

The cable reel is hydraulically driven. Reel speed is adjusted by means of an electric signal from a "floating" wheel measuring actual vehicle velocity. Drive is through a torque limiter in order to avoid excessive cable tension levels.

In front of the reel and spooling device is a sliding, cable-positioned, cable cleaning device comprised of flexible-shaft driven, flexible brushes.

A cable angle sensor is slide-mounted on the leading edge of the dispensing "elephant ear". The unit senses cable vertical angle as an indicator of the tension in the cable. As the shuttle car approaches the tie-point, the unit rotates toward the outside of the car, engaging a limit switch or similar device, as the cable passes the tie-point. This causes the reel to reverse direction so as to pay out cable. The signal can be "programmed" to compensate for car reversals at or near the tie-point.

A horizontal roller and straddling wand are positioned between the cleaning device and the spooling unit to measure changes in vertical angle reflecting changes in cable tension. This signal, the cable angle or displacement sensor on the "elephant ear", and the floating wheel are combined in on-board circuit logic to obtain a single resultant signal which adjusts the torque limiter.

A pulse generator mounted on the spool device measures directly the deployed cable length and causes vehicle automatic shutdown before the cable completely unwinds.

4.2.4 Modular Hydraulic System

The reel is hydraulically driven through a torque limiter, adjusted by a signal from a free-floating, ground-contacting wheel which measures actual shuttle car velocity. The reel is conventional, having a spooling device in front of it to lay the cable evenly as it is wound.

A "hugger" belt unit is located in front of the spooling device to control cable tension. The hugger belts are driven from the reel hydraulic system. The larger surface area of the belts assures more accurate control of tension in the cable because there is less belt slip.

A sliding-type, cleaning unit is mounted forward of the hugger belts before the cable leaves the car. The sliding unit permits cable movement laterally during cleaning and spooling.

The hydraulic power system is stored entirely in two removable packages; one at the reel well and another in a compartment adjacent but in front of the reel well, modified to a more rectangular position. The pump-motor and valve are located in the reel well compartment. The basic hydraulic power supply is in the second package, protected by reinforced structure from damage due to shuttle car collision with mine obstructions.

A side guide (traversing guide) is used to keep the cable out of the vehicle path, regardless of vehicle direction of motion. The guide uses switches with straddling wands to determine side angle and to signal when reel reversal is required. Vertical angle sensors are used in conjunction with the cleaning device as a backup tension monitoring system.

An end of cable pulse generator is mounted on the hugger belts to signal complete vehicle shutdown before the cable unwinds completely from the drum. The pulse generator defines actual length of cable desployed.

4.2.5 All-Electric System

In this concept the cable reel is driven by two electric motors through a mechanical differential. A low horsepower, high torque drive train provides the static torque through a magnetic torque limiter. A higher horsepower, reversible drive train provides the accelerate/decelerate torque, as well as the running steady-state torque requirements of the cable reel.

The following signals will be generated by utilizing transducers and components mentioned in previous concepts:

- Vehicle ground speed
- Cable tension
- Reeled radius
- Cable angle (horizontal)

A logic module will convert the torque command signal (calibrated in tension units) plus the feedback signals into a tension level, properly limiting free cable velocities and accelerations.

A cable guide unit with side and vertical angle sensors provides a signal to stop or reverse the reel motion as the shuttle car approaches the tie-point, also preventing the car from running over its cable.

A pulse generator is used to measure deployed cable length and to automatically stop the shuttle car before the cable is totally unwound.

4.3 SYSTEM EVALUATION

Suitable criteria were identified to assess cable reel system performance and physical objectives. These criteria are listed in Figure 4.7. Since all criteria are not of equal importance to the performance of the shuttle car cable reel system and, therefore, in the evaluation of concepts, each parameter has been assigned a "factor weight" to properly reflect parameter priorities. In addition, Figure 4.7 tabulates some of the subordinate considerations involved in the assessment of each major evaluation factor.

Subcontractor technical personnel having an association with this program were requested to evaluate the five cable reel system improvement concepts in the defined

Evaluation Factor	Factor Weight
PERFORMANCE	30
. Power Consumption	
. Cable Temperature Control	
. Cable Tension Control	
- Monitor	
- Adjust	
- Response Time	
- Acceleration	
. Induced Cable Flexure	
. Load Condition at Tie Point	
. Susceptibility of Running Over Cable	
. Vehicle Speed Characteristics/Cable Handling Rate	
. Safety Improvement	
- Personnel	
- Equipment	
- Hazard Indication	
- Emergency Shutdown	
SIMPLICITY	30
. Number of Adjustments Required for Operation	
. Number Moving Parts	
. Maintenance Accessibility	
. Maintenance Complexity/Time	
RELIABILITY	20
. Ruggedness	
. Contamination Susceptibility (Hydraulic System)	
. Adjustment or Failure Frequency (MTBF)	
. Life	
. Repeatability	
PHYSICAL	10
. Volume	
. Weight	
. Distribution	
COST	10
. Purchase/Installation	
. Operation	
. Maintenance	
. Life	
TOTAL	100

FIGURE 4 .7 SYSTEM EVALUATION CRITERIA

objective areas. Because of the complexity of the overall cable reel system, it was suggested that each system alternative be rated on a scale of 1 to 10 for each evaluation factor and that these ratings then be multiplied by the factor weight. Thus, the final rating would be on a basis of 0 to 1,000. It was also suggested that, if desired, the levels of performance, simplicity, etc., of current underground shuttle car cable reel systems might be considered as a factor rating of 5. Concepts rated to be better or worse than current practice could be rated above or below 5, respectively, based on their relative superiority or inferiority thereto.

The end result of the evaluation provided a rank ordering of the five composite system concepts with the concept(s) scoring the highest being the "best". Staff composite (average) ratings for each evaluation factor and the relative merit rating of each concept are summarized in Figure 4.8, System Evaluation Matrix.

4.4 EVALUATION REVIEW

Further, in depth, review of the evaluation results indicated no clear-cut "best" system concept and no improvement concept far superior to existing equipment. Since concepts for the improvement of major operating and equipment problems had been generated, it appeared that perhaps the most efficient system combination had not been identified.

Major criticisms of the several candidate system concepts were identified as:

- "Fifth" wheel: Proper location for accurate car motion measurement; accessibility difficulty at center of vehicles; additional maintenance area.

- Side angle sensor: Applicability of angle measurement over entire work area, particularly around ribs.

- Cable traversing guide: Not practical on side of vehicle because of mine obstructions; must be protected, and must flex as discharge boom is raised or lowered.

- Complexity: Design must maintain maximum system simplicity.

Evaluation Factor	Factor Weight	System Concept Ratings*				
		Capstan Drive	Inside-Out Motor	Reel Logic System	Module Hydraulics	All Electric
Performance	30	156	186	172	188	192
Simplicity	30	145	172	179	147	143
Reliability	20	98	125	114	111	129
Physical	10	43	55	57	39	53
Cost	10	42	45	50	46	53
Total		484	583	572	531	570
Relative Rank		5	1	2	4	3

*Composite of subcontractor technical evaluators

FIGURE 4.8 SYSTEM EVALUATION MATRIX

In an attempt to further optimize cable reel system improvement, it was determined that Concepts Nos. 2 and 5, two of the three system improvement concepts in the "best" category, tended to best alleviate remaining problem areas. The judicious combination of components of these two systems can eliminate most of these deficiencies. Thus, another system concept was developed.

The resultant, recommended, composite cable reel system is essentially an all-electric system utilizing multiple system indicators to predict and activate cable reel motion requirements. This sixth cable reel system concept is described in Section 5.0 and is illustrated in Figure 1.1.

SECTION 5.0

RECOMMENDATIONS

The cable reel concept recommended for further investigation combines electronic/electrical control of the reel drive, multiple sensors, and a traversing guide. It is shown in the artist concept in Figure 1.1 and the potential improvements in problem areas are given in Table 1.2. This concept represents further refinement of ideas described in Section 4.0, although considerable further development is necessary before such a system should be fabricated and subjected to underground evaluation on a shuttle car.

5.1 CONCEPT DESCRIPTION

In this concept, as originally defined, the cable reel is driven by two electric motors through a mechanical differential. One of these motors is a low horsepower, high torque drive which provides a static torque (cable tension) through a magnetic torque limiter. The second motor, a higher horsepower, reversible drive, provides the dynamic torque required for reel acceleration and deceleration as well as the steady-state dynamic load.

A preliminary layout of the two motor configuration on the shuttle car is shown in Figure 5.1. It is readily apparent that component volume requirements are too large to fit these into the typical shuttle car. Further analysis was then aimed at accomplishing the reel drive function with one motor, rather than two motors and a differential. Also, the size requirement for the motor was considered. Preliminary calculations, contained in Appendix "E", show that a 10HP motor can provide the necessary drive to achieve the reel acceleration and deceleration requirements. Thus, a single motor is mounted immediately above the reel in Figure 1.1. Both the two motor configuration and the single motor configuration are described in Section 5.2.

A number of vehicle/cable properties are sensed for use in cable reel control.

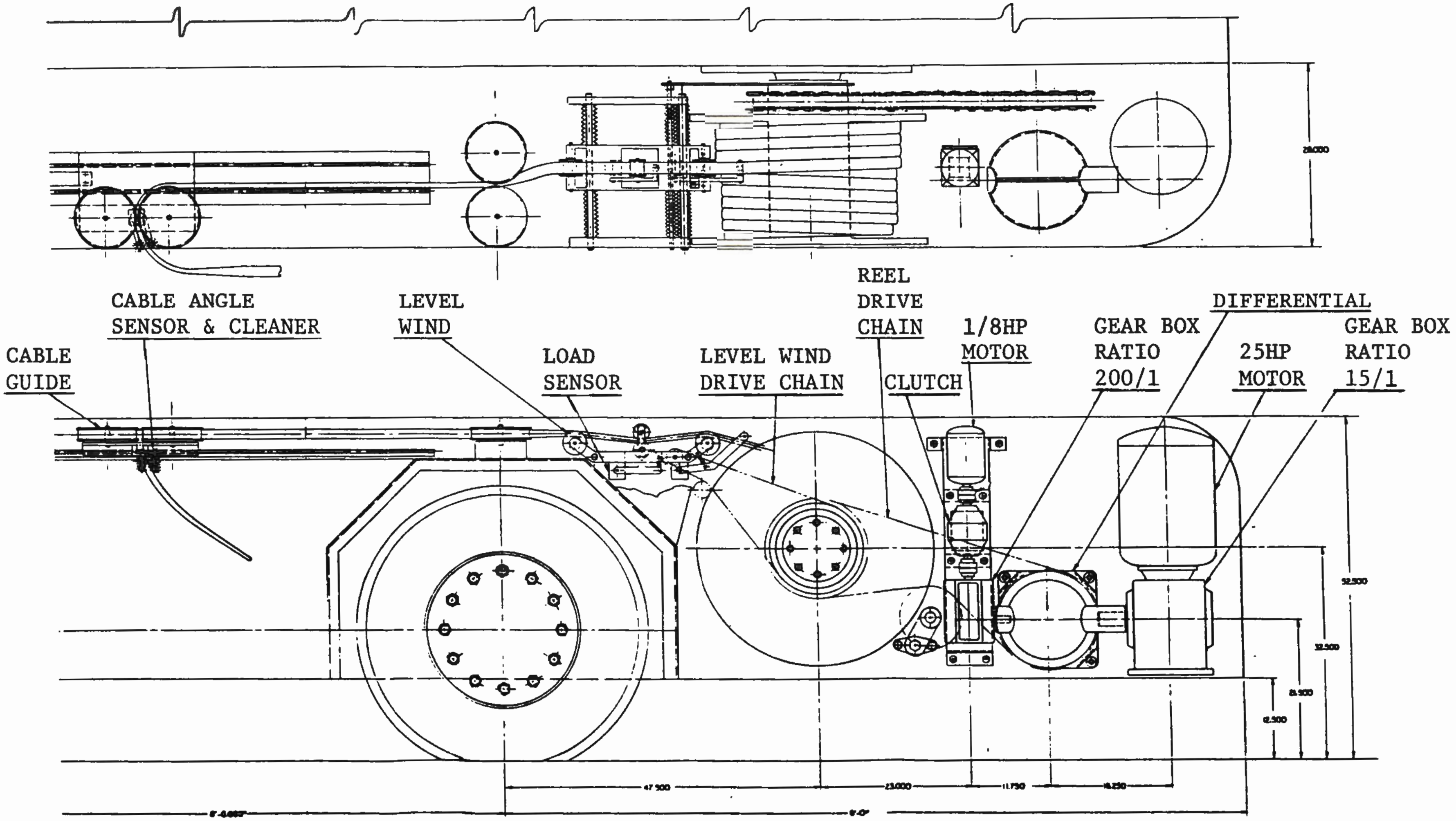


FIGURE 5.1 TWO MOTOR DRIVE PRELIMINARY CONCEPT LAYOUT

- Vehicle wheel speed indication (not ground speed). Simple indication of direction (forward or reverse) and motion; may be wheel, axle, gear, or accelerator "take-off".

- Cable tension. A triple roll tension sensing device, similar in form to a wire straightening device, in which a load cell is used to measure tension in the cable.

- Reeled radius. Will indicate unreeled length of cable using a proximity sensor to count reel rotations.

- Cable angle (horizontal). A simple side angle sensor, described below, indicates the approaching tie-point by contacting a limit switch as the angle with the tie-point changes. This sensor can be locked out or turned "off", if desired, when working "around corners", since reel reversal is not required.

A logic module converts the command signal (calibrated in cable tension units) plus the combined feedback signals (above) into a tension level with properly limited free cable velocities and accelerations. This also permits the manual selection of desired tension and feedback levels.

A cable traversing guide is mounted on the top of the shuttle car on the same side as the cable reel. This guide is approximately 16 feet long and has a flexible joint near the conveyor boom pivot. The guide is protected along most of the length. At the discharge end this protection resembles the "elephant ears" on a conventional shuttle car.

The level wind in this concept is a pair of sheaves in a vertical plane that are driven via the reel and are located just above and on the frame side of the reel. The cable comes off the reel through this heavy duty level wind into the duct area behind the guide rail for the traversing sheaves. As the traversing sheaves move freely from one end of the guide to the other, the cable bends around the opposite sheave in the level wind pair.

As described in Section 3.4.3, the cable guide need not be powered. One purpose is to take up cable slack when the cable reel motion lags behind the cable motion. A "hose reel"-type of spring of approximately 100 pounds force, mounted at the guide end opposite to the cable reel, is adequate for this purpose. Free traverse in the guide frame permits the cable to be released at all times at the "tie-point end" of the car and provides an additional time contingency to permit the reversal of reel motion and velocity as it passes the tie-point.

Since the angle sensor (not shown in Figure 1.1) must be placed at the cable discharge point (from the guide), an angle sensor straddles the cable and, as the cable angle varies, indicates tie-point location. Further, this angle sensor uses "dead roller" brushes as the side "straddles" to provide the additional function of cable cleaning.

A pulse generator mounted on the spool device measures directly the deployed cable length and causes vehicle automatic shutdown before the cable completely unwinds. This count can be initialized by the operator by driving the car close to the tie-off point and pressing a button.

5.2 SYSTEM OPERATION

The cable tension control system is basically a force-balance servo system which produces cable tension at the level selected, by the operator or mechanic, on the total tension set point. A functional block diagram of this cable tension control system is shown in Figure 5.2.

Two separate torque paths are combined mechanically prior to being coupled to the input sprocket or shaft of the cable reel. These two torque paths utilize conventional, 3-phase, electric motors to produce torques and motions at the cable reel to maintain the desired cable tension during vehicle conditions of rest, acceleration, deceleration, constant velocity, reversal of direction, and passing of the tie-point.

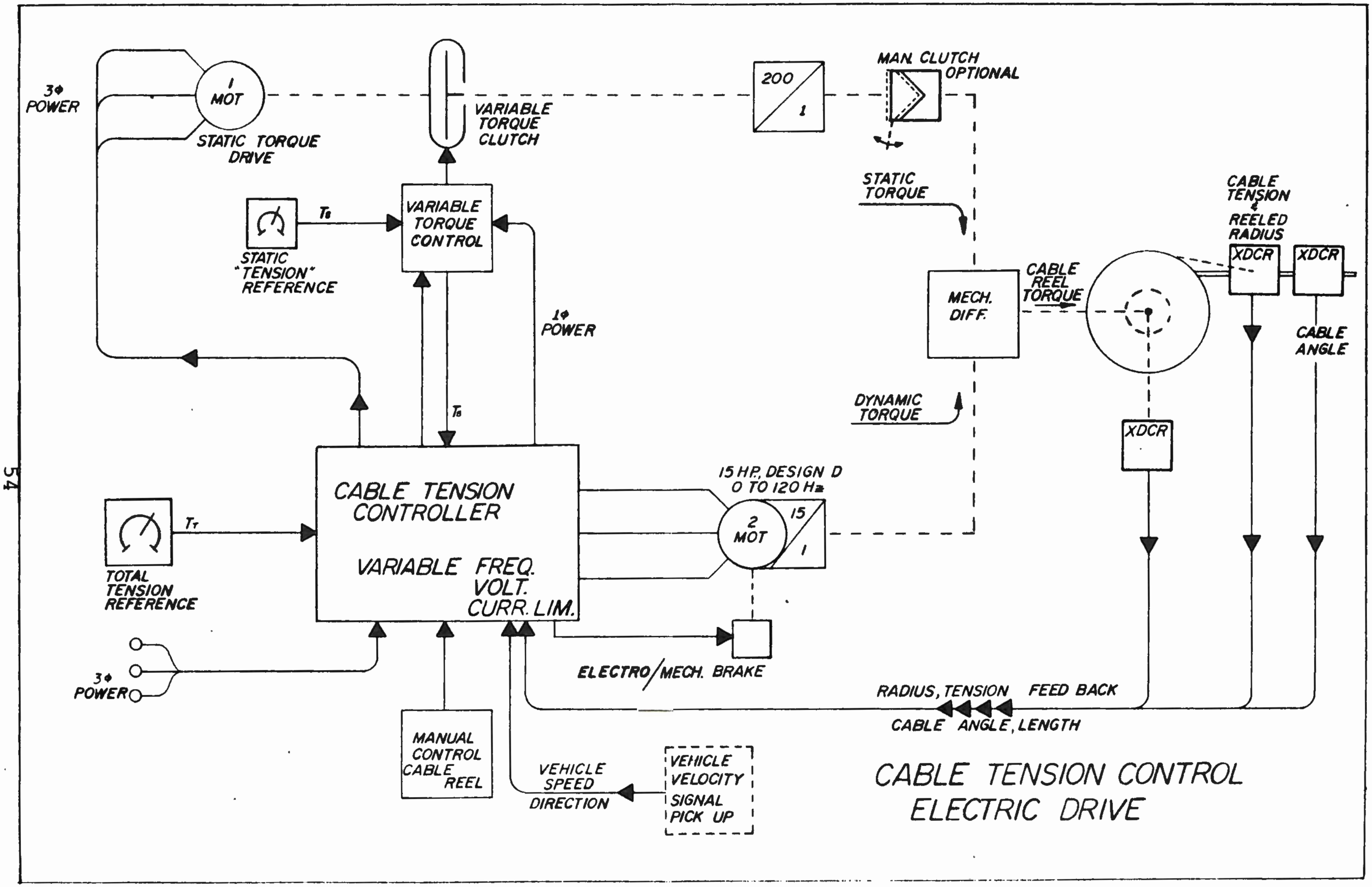


FIGURE 5.2 CABLE TENSION CONTROL SYSTEM BLOCK DIAGRAM

The static torque system is a low horsepower, very low RPM, high torque system used to provide cable takeup and tensioning when the vehicle is stationary. The degree of static torque is electrically adjustable over a range of approximately 2% to 100% of maximum. This system is operated "open loop" and can be manually reversed for maintenance purposes. It is automatically set to minimum torque by the control logic during certain conditions of dynamic torque. A feedback signal from the reeled radius transducer is used to convert the static torque command signal into a static tension signal based upon the measured radius or torque arm of the reeled cable. The mechanical output of the static torque system is connected as one of the inputs of a mechanical differential.

The dynamic torque system is the higher horsepower, high RPM (variable and reversible), high torque system used to provide cable tensioning when the vehicle is moving or changing direction (forward/reverse). A current source inverter is used to power a standard induction motor. The "total tension" signal is a "current limit" signal to the inverter and the maximum speed or frequency signal is determined by the reeled radius feedback signal. The reeled radius signal will also be used to convert the torque signal to a cable tension signal, as was done for the static torque system. The mechanical output of the dynamic torque system is connected to the other input to the mechanical differential.

The final mechanical drive to the cable reel is the difference between the dynamic torque and the static torque signals, $T_R = T_D - T_S$, where T_R is reel torque. Because the available speed of the static torque system is purposely low, 8 to 16 RPM, it will act essentially as a locked shaft during dynamic torque operations.

For tie-point crossing the horizontal cable angle sensor generates an extra torque boost signal from the inverter. The extra torque required from the motor must be achieved by "oversizing" the motor and selecting a particular design curve (Design B, C, or D) to function compatibly with the inverter operation.

For maintenance convenience, a manually operated cone or toothed "clutch" is released, permitting manual handling of the cable for cable repairs. A power-on, manual operation mode permits slow take-up or unwinding of cable by use of the static torque (low RPM) system.

This two motor design has many similarities to industial applications so there is a high confidence in achieving the desired performance. However, as stated earlier, the space requirements are too large for the shuttle car. From functional considerations it appeared that a single motor design could be made although the requirements on the motor appear more severe. The motor must provide high torque and operate with electrical drive input while actually rotating in the opposite direction (cable pay out).

A separate blower may be required for cooling the torque motor since the torque motor must operate at varying speeds in either direction as well as at stall.

Figure 5.3 is a functional block diagram of the single motor design. Calculations to determine the required motor size are presented in Appendix "E". These show a 10HP motor to be adequate although a 15HP motor may be desired for extra margin. The recommended system concept illustrated in Figure 1.1 uses this single motor design.

5.3 SYSTEM ADVANTAGES

As intended, this sixth system concept reduces or eliminates several identified deficiencies of the five original system concepts. In addition, the hydraulic reel system is replaced by an all-electric system, thus eliminating inherent contamination and maintenance problems, one of the major objectives of this investigation. Electric motor drives and electrical maintenance requirements are as equally familiar to mine personnel as hydraulic system maintenance.

The system should maintain an approximately uniform trailing cable tension, thus minimizing cable whip and resultant personnel and equipment safety hazards while satisfying all performance objectives of reliability, availability, cable tension and handling rate, and car and reel motion.

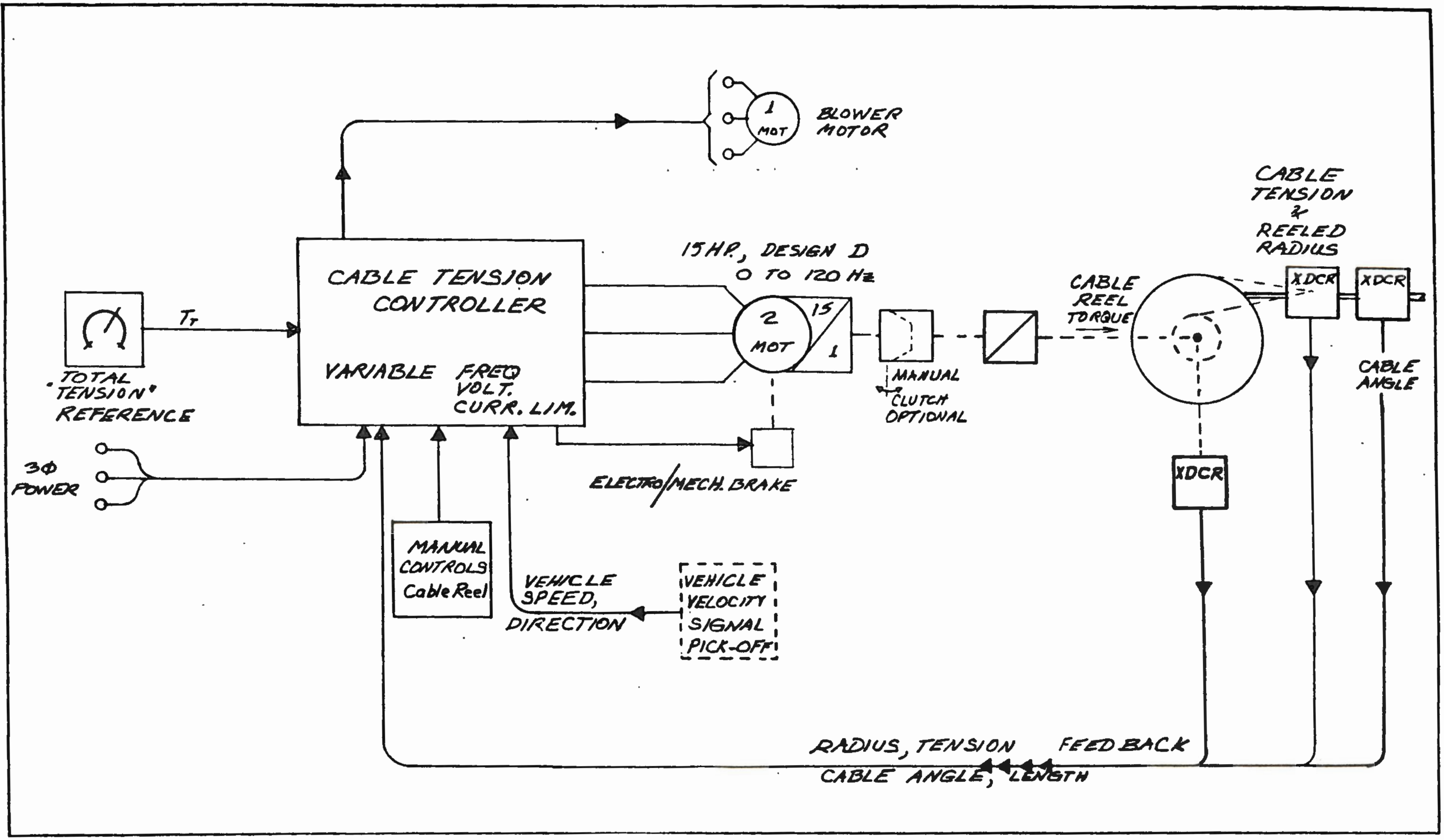


FIGURE 5.3 FUNCTIONAL DIAGRAM FOR SINGLE MOTOR DRIVE

The cable tension controller is contained in a "black box", permitting module replacement (probably more easily than the present hydraulic valve replacement); all feedback signals are supplied by sensors inherent to the equipment being sensed; precise "measurement" is not required.

The traversing guide will provide the two distinct advantages of keeping the cable away from the wheels when backspooling and in taking up slack when peak cable handling accelerations occur. It is recognized that a mine worthy implementation of the traversing guide is a real technical challenge. As presently envisaged, it can be kept within the side contour of the shuttle car and protected on top. The traversing unit is unpowered and the spring life is anticipated as one year or more.

Electronic count of reel rotations can be used to shut down the shuttle car before the cable is completely unwound with the possible cable parting. The operator will have a simple button to push when close to the tie off point in order to initialize the system. Otherwise, there are no operator controls required for the cable reel system.

Any maintenance adjustments of electronic items will be internal to the enclosures. These will be manual controls and adjustments consisting of toggle switches or thumb wheel devices.

APPENDICES

APPENDIX A
READING/REFERENCE LOG

Title	Date or Identification	Content
1. Bu/Mines RFP for this program.	6-12-78	Provides objective, background, scope of work, tentative performance specs, and tentative evaluation test specs. NOTE: Latter is for information only and for consideration during this phase. Test program would follow detailed design and prototype fabrication.
2. Technical proposal in response to RFP	7-13-78	
3. Response to inquiries from proposal evaluation team at meeting of 8-25-78.	8-31-78	Further defines our interpretation of scope.
4. Final Work Plan submitted after award. (Includes an alternate description of Task 5, The Major Task)	2-19-79	
5. Text book summary of shuttle cars.		
6. Product data, specs, and typical costs of shuttle car cable	Vendor literature & quotes	
7. Cable Whip in Shuttle Car Training Cables	Technical Progress Report #83, 10/74	Defines cable payout and takeup torque settings to reduce cable whip. NOTE: Co-author (Conroy) is the Bu/Mines Technical Project Office (TPO) for this job; i.e., our boss. This report is part of the work done by FMC and reporte in PB-235 639 and 640 (Item 20 of this log).
8. Extract of Joy Control Valve Instruction Manual	About 10 years old.	Also provides description of operation.
9. Old Joy Control Valve		Used on export cars.
10. New Joy Control Valve and Reel Ass'y		This is the valve used in Conroy's report (Item 7, above).
11. Snap-Tite Cable Reel Valve	Vendor literature	Allegedly, this is the best item presently available. Major difference, idles at low pressure instead of high. Also, allegedly is more difficult to adjust
12. Inter-Office memo -- Trip to Island Creek Coal, Fies #9 Mine	3-8-79	Summarizes their performance improvement resulting from a conscientious maintenance program and identifies their "experimental" valve as the Snap-Tite
13. Island Creek/Bu Mines correspondence	9-10-76 thru 3-30-77	Summarizes Island Creek's down-time situation, oil contamination, and intention to maintain a maintenance program. Requests Bu/Mines-funded development progra
14. Jeffrey Ram Car Cable Reel Valve	Vendor literature	Parts list and drawing
15. National Mine Service Co. Hydraulic Diagram and Cable Reel Valve	Vendor literature	See Item #17, below.
16. Joy 10SC22A Shuttle Car	Vendor literature and specs	Describes electric system (AC & DC), cable maintenance, and new control valve
17. Another National Mine Service Company Cable Reel Valve		See Item #15, above.
18. Fluid Controls Cable Reel Valve		
19. Patent Search -- Mine Shuttle Cable Reels	2-16-78 (really 2-16-79)	See separate log and folder. Grouped by: . Electrically powered cable reels . Hydraulically powered cable reels . Control valves for hydraulic motor units for cable reels . Means for continuously maintaining tension on the cable wound on a cable reel . Guides to prevent the cable from becoming fouled when being reeled or unreeled from the cable reel . Misc. apparatus related to cable reels
20. "Protection & Troubleshooting of Coal Mine Electrical Cables"	Bu/Mines Contract performed by FMC Corp.	See item #7, above.
(1) Shuttle Car Reel Test Unit	PB-235 639 (10/72)	
(2) Continuous Miner Cable Reel System Design	PB-235 640 (12/72)	
21. "Electrical Materials Analysis -- Mine Cable Splices" -- Annual Report	Bu/Mines Grant No. G0155197 performed by Penn State U. 8-31-76	
22. "Electrical Materials Analysis -- Mine Cable Splices" -- Task Completion Report	-DO- 10-30-77	
23. "Electrical Materials Analysis -- Cable Handling" -- Task Completion Report	-DO- 10-15-77	
24. "Coal Mine Electrical System Evaluation, Vol. I - Continuous Monitoring" -- Annual Report	-DO- PB 283 490; 1-22-77	
25. "Evaluation of Coal Mine Electrical System Safety" -- Annual Progress Report	Bu/Mines Grant No. G0155003 by Penn State U., 1-31-78	
26. Elastimold Mine Splice Kit	Vendor literature	Summarizes crimp connector and molded jacket sleeve in brochure form.
27. "Trailing Cable Splicing -- Acceptance Testing and Training" -- Extract of Report	Bu/Mines Grants Nos. G0101729 and G0135077 performed by Penn State U.	Provides definitive tension and flexibility values to failure of various splice techniques.
28. Miscellaneous dimensional data of various shuttle cars.	Extracts of vendor literature	Representative vehicle configurations for: - FMC Galis Model 6-24 - Joy Model 15SC - NMS Models 488-36 & 488-48 - Jeffrey Model 67 - Joy Model 21SC2 - NMS Model TORKAR 26, 30 & 48 - Joy Model 10SC22 - Joy Models 18SC6 & 18SC9

APPENDIX B
PATENTS LOG

General Technology Area	Patent Number/Inventor (Assignee)/Date	Summary
1. Electrically Powered Cable Reel	2,415,916 - Sloane (Goodman Mfg.), 2/18/47	Cable Reel Switch - Maintains the same torque on the cable reel and drive motor regardless of whether the motor is acting as a motor or a generator or is stalled (idling) -- by cutting a resistance out of the circuit during winding and into the circuit during unwinding or when stopped. Utilizes a hydraulically operated switch relying on the hydraulic drag between two elements.
2.	2,639,101 - Hair (Joy Mfg.), 5/19/53	Reel Drive and Control Mechanism - Provides electric driving motor and resistance to be automatically switched in and out of circuit to reduce current to motor (unwinding) or increase motor current (windup). The no-resistance condition applies for a stationary cable condition -- uses governor device to close switch -- governor rotation taken off reel. Unidirectional drive clutch assures switch only closes on windup.
3.	2,639,336 - Woolf (Joy Mfg.), 5/19/53	Reel Drive and Control Mechanism - Resistance in electrically driven reel motor circuit to assure tension in cable at proper level stationary or winding up or letting off. Monitors vehicle wheel rotation and cable side angle to know if going to or away from the point. Switch can be activated by wheel rotation.
4. Hydraulically Powered Cable Reel	23,300 - Slomer (Goodman Mfg.), 11/28/50	Cable Reel - See Pat. No. 2,665,081. Provides fluid motor drive to a cable reel so arranged that the volume of fluid supplied to the motor for the cable reel will automatically increase as torque on reel decreases; will be automatically decreased as torque on reel increases, using a motor-pump and a back pressure (motor) valve with movable spool.
5.	2,593,367 - Vandertee (Joy Mfg.), 4/15/52	Reeling Mechanism - Reel at front of vehicle with shaft vertical. Rigid guide indicates cable always on one side of tie/connection point (no sheaves are used). Reel is driven by an improved fluid operated reel motor with associated controls. Has automatic fluid bypass so reel may unwind freely. Uses wheel drive fluid tap for control and direction sensing. Windup activated before fluid to wheel motors to reverse drive is applied.
6.	2,601,958 - Baldwin (Joy Mfg.), 7/1/52	Cable Reel Mechanism - Front of vehicle reel (similar to 2,593,367) sliding spool manually positioned by lever. Claims improved motor mount with a pivoted drive to increase or decrease cable tensions by manual screw adjustments. Chain and sprocket drive.
7.	2,639,102 - Ball (Joy Mfg.), 5/19/53	Reeling Mechanism for Power Conductors - Hydraulically driven reel effected by a pump-motor device. Reduces backpressure motor (pump) must work against in windup and reel drives motor as a pump during unwinding. Uses auxiliary pump and group of differentially set relief valves to properly circulate fluid to working components and storage reservoir. Cable tensions similarly controlled. A balanced piston valve mechanism.
8.	2,665,081 - Slomer (Goodman Mfg.),1/5/54	Cable Reel - Automatic control of tensioning of cable during wind-up and unwind by providing a pressure relief valve and a movable control for the PRV in the outlet of the fluid motor when being driven as a pump and condition for immediate cross-over to a cable windup mode. No electrical controls are used -- based solely on fluid pressures and reel direction of rotation. One high pressure valve; one low pressure valve.
9.	2,670,153 - Hair (Joy Mfg.), 2/23/54	Cable Reeling Mechanism - Use of fluid activated valves and gear pumps to achieve correct flow of fluid during windup and let-off (unwind) to prevent excessive cable tensions. Automatically winds or unwinds by pressure in valve or manually adjustable pressure relief valves.
10.	3,250,491 - Stalker (Goodman Mfg.), 5/10/66	Hydraulic Cable Reel Drive Circuit - Improvement in hydraulic drive and associated control circuits for cable reel to obtain desired tension on windup or unwinding cable. Use sensor to define reel direction of rotation and uses the main and auxiliary pumps to constantly supply pressurized fluid to the cable reel motor. One pump driven in accordance with vehicle speed (wheel). Uses high and low pressure relief valves.
11.	3,380,545 - Kemper (Westinghouse Air Brake), 4/30/68	Cable Reel Control Mechanism - Hydraulically operated cable, reel drive and control circuits. Manual selection of mode of operation of reel drive.
12.	3,894,553 - Exley (Joy Mfg.), 7/15/75	Cable Reel Control Valve - Control valve assembly for controlling reversible flow between a hydraulic pump and motor using a combined spool and check valve in a simplified housing.

General Technology Area	Patent Number/Inventor (Assignee)/Date	Summary
13. Control Valves for Hydraulic Motor Units for Cable Reels	2,654,382 - Hair & Ball (Joy Mfg.), 10/6/53	Control Valve Mechanism - Improvements in control valve mechanisms controlled entirely by hydraulic pressure.
14.	2,654,383 - Hopkins (Joy Mfg.), 10/6/53	Control Valve Mechanism - Same as 2,654,382, above.
15.	2,654,547 - Ball & Hair (Joy Mfg.), 10/6/53	Cable Reeling Mechanism - See 2,654,382, above.
16.	2,654,548 - Hopkins (Joy Mfg.), 10/6/53	Cable Reeling Mechanism - See 2,654,383, above.
17.	4,114,827 - Maier (Snap-Tite, Inc.), 9/19/78	Cable Reel Valve and System - Cable reel control valve and hydraulic motor control system. Valve has pump and motor part for reel motor and pressure across ports for automatic bypass to supply tank when cable unwinding or is stopped; automatically diverts full pump flow to reel motor during windup.
18. Means for Continuously Maintaining Tension on the Cable Wound on a Cable Reel	2,090,707 - Sloane (Goodman Mfg.), 8/24/37	Mine Locomotive - Uniform tension objective. Torque on motor varies according to amount of cable on the reel thereby keeping tension on cable uniform; winding or unwinding cuts resistance into or out of circuit for power to reel (two single conductor cables considered).
19.	2,126,172 - Cartlidge (Goodman Mfg.), 8/9/38	Cable Reel - Improved cable reel to properly power reel motor to maintain tension in cable during unwind and windup. Tension to be maintained when vehicle is stationary. Vertical reel (horizontal axis/lateral to car axis = cable axis). Mechanical -- internal brake shoes, spring-loaded, adjusted by center hub rotation opening shoes from contact allows reel to freely wind up cable. When shoes are in contact, unwinding with preset tension allows drum of reel to rotate after friction overcome by tension.
20.	2,759,684 - Cross (General Electric), 8/21/56	Cable Reeling System - Hydraulic motor drive to maintain constant tension on cable during reeling in or out at a sufficiently low level not to damage cable. Manually adjust relief pressure.
21.	3,334,839 - Carlson (Westinghouse Air Brake), 8/8/67 See 3,250,491 and 3,250,492	Cable Reel Tension System - Hydraulic control system to maintain constant tension on cable. Three conditions; wind, unwind, rest = 3 adjustable relief valves. Valving method.
22. Guides to Prevent the Cable From Becoming Fouled When Being Reeled or Unreeled from the Cable Reel	2,589,217 - Ball (Joy Mfg.), 3/18/52	Mine Shuttle Car - Electric motor driven wheels, electric motor drive for the reel. Spooling and two pulleys front of car mount in corner.
23.	2,589,235 - Dudley (Joy Mfg.), 3/18/52	Reeling Device - Guide for cable. Double pulley front corner guide. Hydraulic reel motor.
24.	2,633,309 - Beck (Goodman Mfg.), 3/31/53	Cable Guide - Swing arm through which cable passes holds cable outboard of vehicle when cable trails rearward and prevents cable off-riding sheave. Arm pivoted at vertical centerline of front sheave.
25.	2,690,884 - Beck (Goodman Mfg.), 10/5/54 See 2,633,309, above.	Cable Guide - Swing arm guide direct to spooler, no interim idler sheave. Main sheave can move laterally with spooler as well as guide cable.
26.	3,990,551 - Jamison (Consolidation Coal), 11/9/76	Cable Gathering Device - Drive cable to free layering in a compartment. A support frame extends in front of storage box and can be pivoted to elevate when not driving cable. Hydraulic motor drive of nip rolls. Frictional engagement between rollers and cable prevents cable motion when vehicle stopped. To replace reel-type cable storage and handling system. Circulate air in storage compartment to cool cable.
27. Miscellaneous Apparatus Related to Cable Reel	1,843,504 - Coseo (Jeffrey Mfg.), 2/2/32	Cable Reel - Tie into trolley wire. Horizontal reel on top of mine locomotive, cable tap into overhead trolley wire via guide rolls. Electric reel drive provides tension during payout.
28.	2,515,805 - Simmons (Joy Mfg.), 7/18/50	Reel Mechanism - Automatic clutch for winding (driving) clutch release to unwind or manually payout cable. Reel horizontal. Screw and nut to lift clutch to engagement or lower it to disengage or alternately incline planes and cams.
29.	2,781,456 - Buckeridge (Goodman Mfg.), 2/12/51	Cable Reels for a Mine Vehicle or the Like - Re: 24376. Safety means to prevent payoff of all cable from a reel. Opens switch in vehicle electric drive motor circuit with cable presence detector on reel to stop car.
30.	3,140,063 - Bucklen (Consolidation Coal), 7/7/64	Cable Reel Support - Pivoted double reel for single conductor cables. Horizontal reel.
31.	3,676,614 - Garmong, 7/11/72	Cable Reel - Vertical reel (horizontal axis). Means of reel assembly that permits disassembly for cable repair in mine.
32.	3,943,306 - Aihara & Kimura (Caterpillar Mitsubishi), 3/9/76	Electric Loader With Excessive Unwind Preventive Means - Electric reeler to wind/unwind electric cable. Manually controlled lever for loader speed and direction control. Length of cable unwound defined discretely by limit switch.

General Technology Area	Patent Number/Inventor (Assignee)/Date	Summary
33.	4,108,264 - Tanaka (Kabushiki Kaisha Komatsu), 8/22/78	Cable Take-Up Device for Electric Drive Vehicle - A cable take-up device mounted at the rear of an electric drive vehicle for winding and unwinding a feeder cable. The device controls a winding angle of the take-up cable so as to maintain it constant. A slack angle of the cable is an angle made between a line drawn along the cable in the vicinity of a winding point and a plane including the winding point and being perpendicular to an absolute plane. This slack angle is controlled so as to provide an optimum tension constantly regardless of forward or reverse running speed change or steering of the vehicle.

APPENDIX C

TENTATIVE PERFORMANCE SPECIFICATIONS

IMPROVED SHUTTLE CAR CABLE REEL SYSTEM

1.0 GENERAL

1.1 The cable reel system shall be capable of:

1.1.1 Satisfactory performance as defined herein, with a probability of 90 percent, for 1,000 hours of normal operation in underground bituminous coal mines on a basis of two operating shifts and one maintenance shift per day, when routine maintenance instructions are complied with.

1.1.2 Being repaired or replaced at the underground site of operations, with 90 percent probability, by a crew of two men with hand tools and a powered scoop, within the timespan of one maintenance shift.

1.2 If a hydraulic drive system is employed, provisions shall be made to guard against the addition of hydraulic fluid from a general supply by

1.2.1 Use of special containers for hydraulic fluid.

1.2.2 Other means which assure that the hydraulic fluid cleanliness level remains consistent with proper operation.

2.0 OPERATING CAPABILITIES

2.1 The reel system shall be required to maintain cable tension at any set value between 100 and 300 pounds pull, and in such a manner that in normal operation of the shuttle car in an underground coal mine entry no part of the deployed cable will acquire a velocity greater than 1 foot per second nor experience an acceleration greater than 2 feet per second^2. Payout and rewind cable tension shall be adjustable. Normal shuttle car operation shall include but not be limited to the following:

2.1.1 Maximum acceleration from standstill to full speed of the shuttle car of 3 feet per second per second, whichever is greater.

2.1.2 Crash stops (defined as maximum practical deceleration to full stop) from any speed up to the maximum of 6 miles per hour.

2.1.3 Rapid reversal of direction of motion of the shuttle car from 10 percent of maximum speed in one direction to 10 percent of maximum speed in the opposite direction.

2.1.4 Rapid reversal as in 2.1.3, above, but with a 2 minute period at standstill between reversals.

2.1.5 Drfiting to a standstill from any speed up to maximum with traction drive power off.

2.1.6 Drifting as in 2.1.5, above, but with no power to the car (circuit breaker tripped at power center).

2.1.7 Drifting dowgrade from a standstill to any speed up to maximum with traction drive power off.

2.1.8 Passing the cable tie-point at a distance of 3 feet or more at any speed up to maximum in either direction.

2.1.9 Roll, pitch, and yaw motions at any speed which may be induced by irregularities in the mine floor or by the operator's steering efforts.

2.1.10 Maintaining up to 6 mph vehicle centerline ground speed with the reel located on either the inside or outside of the vehicle turn radius.

2.2 The reel system shall provide storage for sufficient cable to permit a working radius of not less than 750 feet from the cable tie-point.

2.3 The reel system shall be required to produce a level wind of cables containing splices which increase the major diameter of the cable by no more than 12 percent.

2.4 The reel system shall clean the cable during rewind to the extent necessary to assure satisfactory operation within the assigned probability limit.

2.5 The reel system shall provide means of cooling the cable or assuring by other means that at no point in the reeled cable or in the system, when operating at maximum rated conditions, will component temperatures or hot spot temperatures exceed 105 degrees Centigrade, or the temperature rise above ambient exceed 70 degrees Centigrade, whichever is smaller.

APPENDIX D
CONCEPT LOG

SYSTEM AREA	DESCRIPTION	EVALUATION
CABLE REEL	1) CABLE REEL OFF CAR	
	• At or near distribution panel	• Decreases car weight/increases payload
	• May be skid mounted	• Away from "dirtier" area
	• May be connected in service to another reel	• Easier to clean and cool
		But: • Cable must be dragged as car moved
	2) OFF-CAR REEL with small reel on car as spring-wound shock absorber	
	3) USE TENSION CONTROL/BRAKE DEVICE ON REEL PAYOUT	• Maintain constant cable tension
	a) Tension Control Idler	
	b) Pressure feed rolls and floating roller	
	c) Tension/brake beam	
	4) WINDLASS CABLE REEL DEVICE	• Prevents slack/whip in cable
	5) INTERNAL STORAGE CABLE REEL ASSEMBLY	• Prevents slack in cable
	6) FLAT COIL REEL	• Eliminates reel wind inertia
	7) CABLE TENSIONING (AND FEEDING) DEVICES	• Prevents slack/whip in cable
	• Pinch rolls	
	• Traction belt(s) and pressure roll	
	• Bull drum or capstan	

SYSTEM		DESCRIPTION	EVALUATION
	8)	VERTICAL AXIS BULL DRUM AND STORAGE REEL	• Maintains uniform system tension • Eliminates directional delay passing tie-point
	9)	SLAVE REEL ROTATION TO DRIVE WHEEL ROTATION	• Requires minimum wheel resistance to eliminate "false signal" from slipping or bouncing
	10)	SLACK ANGLE CONTROLLER (JAPANESE PATENT)	• Provides optimum tension control
ALTERNATE POWER	11)	AC MOTOR AND MAGNETIC CLUTCH	• Provides adjustable torque control • May be assembled into a total cable tension system by adding a larger corner (pillar) sheave acting as capstan, thus providing constant torque because of a single cable layer on drum
	12)	SPRING POWERED REEL WITH CENTRIFUGAL BRAKE	• Eliminates response delay
	13)	BATTERY OR FUEL CELL-POWERED, OR BATTERY POWERED TENSION SYSTEM WITH CONTINUOUS RECHARGE	
	14)	TROLLEY CAR WITH EITHER BOOM CONNECTOR OR PANTAGRAPH ASSEMBLY	• No reel • No Trailing Cable But, may limit lateral travel
	15)	PERISTALTIC ("TUG-OF-WAR") CABLE DRIVE	• Provides both drive and feed pressure, giving constant cable tension
	16)	LINEAR INDUCTION MOTOR	• Provides constant cable tension by reducing response time

SYSTEM AREA	DESCRIPTION	EVALUATION
CABLE FACTORS	17) TRAILING CABLE ROOF MOUNT	• Eliminates damage by equipment • May eliminate whipping if intermediate supports used
	18) PVC ADJUST-A-POST	• Protects cable at pillar corner
	19) CABLE CLEANING DEVICES	
	Rotary brush	
	Fixed group of brushes	
	Squeezable	
	Brush trough (may be combined to provide a whip damper	
	20) CONDUCTOR CONCEPTS	
	a) Liquid	
	b) Layered foil (instead of rounds)	
	c) Copper plated steel	• Greater strength
	d) Inbedded steel cable	• Acts as tension absorber May also provide failure prediction
	e) Imbedded steel braid (instead of fabric)	• Acts as tension absorber
	f) Viscous coupled drive to reel	

SYSTEM AREA		DESCRIPTION	EVALUATION
CABLE FACTORS (cont'd)	21)	CABLE COOLING CONCEPTS	• Air cooling requires additional equipment
		a) Ventilated reel core; slotted construction and forced air	
		b) Liquid cooling channels integral with cable cross section	• Liquid rotary union required at reel
		c) Forced air ventilated reel compartment	
		d) Recirculating coolant in alternate turns of cable and hose	
		e) Forced ventilation of festooned storage	
MAINTENANCE	22)	FLUID REFILL (TRANSFER) BY ENCLOSED SYSTEM, AIR PRESSURE, FILTER "TRAP"	
	23)	MODULAR REPLACEMENT OF OIL RESERVOIR AND FILTER	
	24)	FINER FILTRATION OR "FORGIVING" COMPONENT ORIFICES	
	25)	CABLE REPAIR CONCEPTS	
		a) Push lock device	
		b) Interleaf splicing fingers with barbed center blade	
		c) Buried center cover with outer end bands to provide tape lock under bands	
		d) Buried center double tapes with end bands	
		e) 3M "U" contact principle	
		f) Turnbuckle device	

APPENDIX E

REEL DRIVE MOTOR CALCULATIONS

The basic drive system is simplified in Figure 1, below showing the cable reel being driven through a 15:1 speed reducer by an induction motor. The induction motor is powered by a Variable Frequency Inverter which can supply constant volts/hertz from 12 Hz to 60 Hz and constant voltage from 60 Hz to 120 Hz. The % Rated Torque and % Rated Horsepower of the motor versus % Base Speed is shown in Figure 2.

The Running Torque at the Reel = $T_c = (F)(R) = \frac{(141\ \text{lb.})(17.85\ \text{ft.})}{12} = 210$ lb.ft. @ 84 RPM.

The Running Torque required from the motor = $T_{2r} = \frac{210}{15(\eta)} = \frac{14\ \text{lb.ft.}}{(\eta)}$ @ 1260 RPM

The Static Torque, Ts also = 14 lb.ft. @ 0 RPM at the Reel and $\frac{14}{15(\eta)}$ at the Motor.

To accelerate the reel as the vehicle accelerates requires an Acceleration Torque, $T_a = \frac{(WK^2)(\Delta N)}{308\ t}$.

Using WK^2 = 2000 lb.ft.^{2}
ΔN = 84 RPM
Δt = 4.8 sec.
Ta = 114 lb.ft. from 0 to 84 RPM

The corresponding Motor Torque for normal acceleration = $\frac{114}{15(\eta)} = \frac{7.6\ \text{lb.ft.}}{\eta}$ from 0 to 1260 RPM.

As the vehicle passes the cable tie point at 12 ft. per second with 3 ft. clearance, the cable reel must change direction of rotation from reeling-in to paying-out cable in approximately 1.2 seconds.

Using WK^2 = 2000 lb.ft.^{2}
ΔN = -84 RPM to +84 RPM = 2(84)RPM = 168 RPM
Δt = 1.2 sec.

The Tie Point Torque, $T_{tp} = \frac{(WK^2)(\Delta N)}{308\ t} = 909$ lb.ft. in the pay-out direction.

Because Reel-In Torque is still required, a net Ttp of 909 - 210 or 699 lb.ft. of TP "Impulse Torque" is required as the tie point is passed.

The corresponding motor torque is $\frac{699}{15(\eta)} = \frac{46.6\ \text{lb.ft.}}{(\eta)}$ at 1260 RPM.

To summarize, the motor torques at Reel Full:

$T_s = \frac{14\ \text{lb.ft.}}{\eta}$ @ 0 RPM

$T_a = \frac{7.6\ \text{lb.ft.}}{\eta}$ @ 0 to 1260 RPM

$T_r = \frac{14\ \text{lb.ft.}}{\eta}$ @ 1260 RPM

$T_{tp} = \frac{46.6}{\eta}$ lb.ft. @ -1260 RPM to 1260 RPM

Using $\eta = 0.7$,

Ts = 20 lb.ft. @ 0 RPM
Ta = 10.9 lb.ft. @ -1260 to +1260 RPM
Tr = 20 lb.ft. @ 1260 RPM
Ttp = 66.6 lb.ft. @ 1260 RPM.

The corresponding motor horsepowers to drive the full reel are $HP = \frac{TN}{5252}$, so that

HPs = 0
$HPa = \frac{(10.9)(1260)}{5252} = 2.62$ @ 0 to 1260 RPM
$HPr = \frac{(20)(1260)}{5252} = 4.8$ @1260 RPM
Peak $HPtp = \frac{(66.6)(1260)}{5252} = 16$ @ 1260 RPM

However, the motor must also run at (233)(15) RPM or 3495 RPM when the reel is near empty. The motor torques would then be $Tr = 20 \left(\frac{1260}{3495}\right) = 7.21$ lb.ft. at 3495 RPM because of decreased reeled radius.

Ts = 7.21 lb.ft. @ 0 RPM
$Ta = 10.9 \text{ lb.ft. } \frac{(WK^2 \text{ empty})}{(WK^2 \text{ full})} = 10.9 \left(\frac{200}{2000}\right) = 1.09$ lb. @ 0 to 1260 RPM

$Ttp = 66.6 \text{ lb.ft. } \left(\frac{200}{2000}\right) = 6.66$ lb.ft.

The corresponding motor horsepower to drive the near empty reel are $HP = \frac{TN}{5252}$, so that

HPs = 0
$HPa = \frac{(1.09)(3495)}{5252} = 0.725$ @ 0 to 3495 RPM
$HPr = \frac{(7.21)(3495)}{5252} = 4.8$ @ 3495 RPM
Peak $HPtp = \frac{(6.66)(3495)}{5252} = 4.43$ @ ± 3495 RPM

A 1740 RPM 5 HP induction motor has a rated full load torque of $Tfl = \frac{5252(HP)}{N}$

$Tfl = \frac{5252\ (5)}{1740} = 15.09$ i.e. 15 lb.ft.

Using a drive line efficiency of $\eta = 0.7$ as before, the Running Torque, Tr = 20 lb.ft. with a full reel.

$\frac{20}{15} = 1.33$, a 33% torque overload

If $\eta = 0.9$, then $Tr = 20\left(\frac{0.7}{0.9}\right) = 15.6$ lb.ft.

$\frac{15.6}{15.09} = 1.034$, @ 3.4% torque overload.

Ttp 66.6 lb.ft. if η = 0.7
2 (Tfl) = 2(15) = 30 lb.ft. @ 80% speed
3 (Tfl) = 3(15) = 45 lb.ft. @ near stall.

A 1756 RPM 7½ HP Induction Motor has a rated full load torque of

$$\text{Tfl} = \frac{5252(7.5)}{1756} = 22.4 \text{ lb.ft.}$$

$$\frac{\text{Tr}}{\text{Tfl}} = \frac{20}{22.4} = 0.89 \text{ i.e. 11\% torque "safety"}$$

Ttp = 66.6 lb.ft. if η = 0.7

2(Tfl) = 2(22.4) = 44.8 lb.ft. @ 80% speed

3(tfl) = 3(22.4) = 67.2 lb.ft. @ near stall i.e. adequate for reel drive.

A 7½ HP 1756 RPM Motor has a motor inertia of approximately 0.62 lb.ft.^{2}. The reflected Reeled Cable inertia = $\frac{2000 \text{ lb.ft.}^2}{(15)^2} = \frac{2000}{225}$ = 8.9 lb.ft.^{2} at the motor shaft.

If the gear box and coupling add another 1 lb.ft.^{2} at the motor, then the motor load inertia is -

$$\begin{array}{l} 8.9 \\ 0.62 \\ \underline{1.0} \\ 10.52 \text{ lb.ft.}^2 \end{array}$$

At the tie point, the motor must also accelerate the additional 0.62 + 1.0 or 1.62 lb.ft.^{2} from -1260 RPM to +1260 RPM in 1.2 seconds which requires a torque, $\text{Ttp}_m = \frac{(1.62)(2)(1260)}{308\ (1.2)}$ = 11 lb.ft.

Adding this 11 lb.ft. to the 66.6 lb.ft. = 77.6 lb.ft. of torque the motor must produce.

$\frac{77.6}{22.4}$ = 3.46 (Tfl) i.e. not practical.

If η = 0.8, Ttp = $\frac{46.6}{\eta} = \frac{46.6}{0.8}$ = 58.3 lb.ft.; 58.3 + 11 = 69.3 lb.ft.

$\frac{69.3}{22.4}$ = 3.09 i.e. Marginal Torque capacity for Design 'D' Induction Motor.

A 1750 RPM 10 HP Induction Motor has a rated full load torque of Tfl = $\frac{5252(10)}{1750}$ = 30 lb.ft. and a Rotor WK^2 = 0.97.

$$\begin{array}{ll} WK^2 = & 8.88 \text{ Load} \\ & 0.97 \text{ Rotor} \\ & \underline{1.00} \text{ Gear Box} \\ & 10.85 \text{ lb.ft.}^2 \end{array}$$

$$\text{Ttp} = \frac{(10.85)(2)(1260)}{308\ (1.2)} = 74 \text{ lb.ft.}$$

$\frac{74 \text{ lb.ft}}{30}$ = 2.46 i.e. Adequate

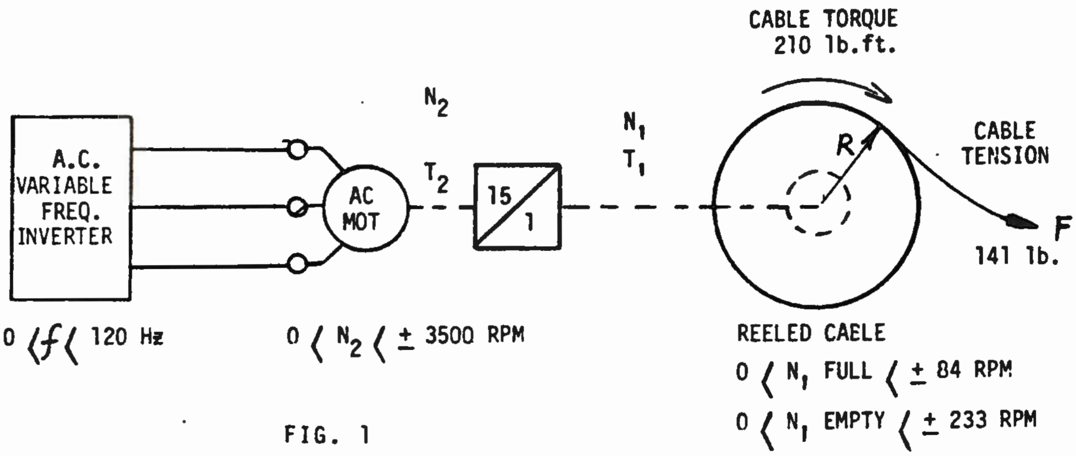


FIG. 1
SIMPLIFIED DRIVE SYSTEM

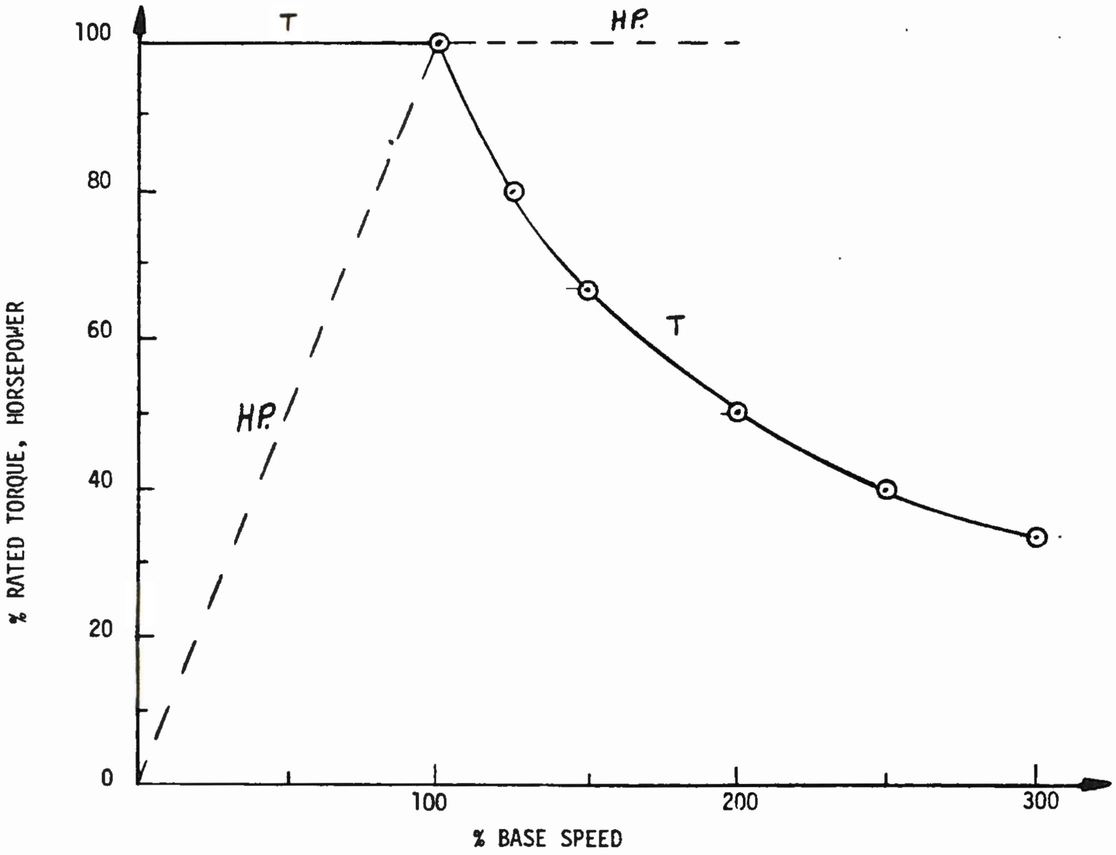


FIG. 2 - TYPICAL MOTOR CURVES