

APPLICATION OF A SUSPENSION ROPE BRAKE TO A SINGLE ROPE MINE HOISTING SYSTEM

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ABSTRACT

In response to mine hoisting system accidents, regulatory agencies have issued mandates and policy directives requiring supplemental ascending overspeed protection. These regulatory initiatives have influenced the development of auxiliary emergency braking systems. Attention has been focused primarily on elevators which are equipped with multiple ropes. This paper discusses the application of a suspension rope brake to a single rope mine hoist. Technical challenges associated with accelerated rope brake lining wear and suspension rope lubrication are addressed.

INTRODUCTION

Mine elevators and personnel hoists provide a lifeline for miners at more than 360 mines nationwide[1]. The hoisting system transports mine personnel through an isolated corridor during routine operations or life threatening emergencies. The potential risk of injury is great if the hoisting system fails. Therefore, a safe, reliable hoisting system is essential to the well being of the miners.

In mining history there have been two well documented investigations of mine hoisting systems crashing in the upward direction [2], [3]. These accidents occurred on counterweighted hoisting systems when the mechanical brake failed while the cage was empty. This allowed the counterweight to fall to the bottom of the shaft, causing the car to overspeed and crash into the overhead structure. The accidents were initially believed to be isolated incidents. However, research covering a 5-year period, showed there were over eighteen documented cases of ascending elevators striking the overhead structure [4].

Rules and regulations applying to elevator safety have come under review in response to these accidents. The Canadian Elevator Safety Code and the Pennsylvania Bureau of Deep Mine Safety have recently revised their regulations and policies to require supplemental ascending car overspeed protection. As a result of this initiative, a new generation of braking systems has been developed and applied to mine elevators and hoists.

Several supplemental emergency braking systems can be applied to mine hoisting systems. Some of the proven systems are counterweight safeties, electrical dynamic braking, and a pneumatic rope brake system. The application of these braking systems to multiple rope hoisting systems is discussed in other literature [5], [6]. The purpose of this paper is to discuss the application of these systems to single rope mine hoists.

The electrical dynamic braking system is inherently unaffected by the number of suspension ropes and has been successfully applied to a single rope mine hoist [7]. However, the application of the rope brake on a single rope hoist has presented technical challenges. This paper will discuss the control, design, and testing of the world's first application of a suspension rope brake to a single rope mine hoist. Problems with accelerated rope brake lining wear and excessive suspension rope lubrication will be addressed. The dynamic performance will be compared to rope brake installations on multiple rope hoisting systems.

CASE STUDY: SINGLE ROPE MINE HOIST

The first installation of a Bode rope brake¹ on a single rope mine hoist was evaluated January 30-31, 1992. The pneumatic rope brake was installed on a ground mounted hoist which operates with a cage in balance with a counterweight in a vertical shaft. The drum is designed to wind an "under" and "over" 1-1/2 inch flattened strand hoist rope in a single layer. The drum is helically grooved to wind 20.4 live turns, 6 dead and 6 cutting turns, plus 4 turns between ropes. The drive is arranged for SCR controlled single D.C. motor drive through a double reduction reducer. The controls are either semi-automatic or manual by operation from the control panel. This hoist was commissioned by the federal and state regulatory agencies on April 12-13, 1984.

Hoist Mechanical and Electrical Specifications

Hoist Distance	:	571 Ft. - Personnel/Materials
D.C.Motor	:	300 Horsepower, 500 Volts DC, 490 Amperes, 400 rpm
Drum	:	110" Diameter x 58" Face
Hoist Ropes	:	Two - 1-1/2" Flattened Strand 6 x 30 Fiber Core, Galvanized, Performed, Lang Lay, Breaking Strength 235,000 lb.
Personnel Load	:	7,875 lb.
Material Load	:	10,750 lb.
Weight of Cage	:	13,000 lb.
Weight of Counterweight	:	17,250 lb.
Weight of Rope	:	4,700 lb. - 3.95 lb./feet
Speed of Hoist	:	600 fpm
Speed of Motor	:	467 rpm @ 600 fpm
Speed of Drum	:	20.55 rpm @ 600 fpm
WR ² of Hoist	:	1,098,340 lb. - ft ²
Drum Brakes	:	Four - Disc Brake Units, Spring Applied Pressure Released, Two Discs, Two Units Per Disc.
Lilly Controller	:	One - Model "C" Lilly Controller Man Safety
Safety Catches	:	Instantaneous Type, Activated by Slack or Broken Rope

¹Use of brand names is for identification purpose only and does not imply endorsement by the Mine Safety and Health Administration.

Rope Brake Design

The rope brake grips the suspension ropes and stops the hoist when an overspeed of 15% is detected or the cage moves away from the landing when it is not under control of the hoist motor.

The pneumatic design is identical to the model 580 described in the literature [6]. When the rope brake is activated, a set of magnetic valves direct pressurized air from the compressor tank into the rope brake cylinder. The air pushes the piston inside the rope brake cylinder and forces a movable brake pad toward a stationary brake pad. The suspension rope is clamped between the two brake pads. The rope brake is released by energizing the magnetic valves, which vent the pressurized rope brake cylinder to the atmosphere through a blowout silencer. The brake pads are forced open by six coil springs.

The force exerted on the suspension rope equals the air pressure multiplied by the surface area of the piston. The rope brake model number 580 designates the inner diameter of the brake cylinder in millimeters. This translates into 409.36 in² of surface area. The working air pressure varies from 90 to 120 lbf/in². The corresponding range of force applied to the suspension rope is 36,842 to 49,123 lb. The static force experienced by the suspension rope on the cage sheave, under fully loaded conditions is 26,000 lb. Therefore, the ropes experience up to 89% greater force during application of the rope brake under emergency conditions, than normally encountered during full load operation.

Rope Brake Installation

The rope brake was installed in a control room constructed in the hoist headframe directly below the cage suspension rope sheave as shown in Fig. 1. The control room contains the complete rope brake system, including the rope brake, control logic, and air compressor. The rope brake safety relay contacts were wired into the hoist control below through conduit. Heaters were installed in the rope brake control room to regulate the temperature during cold weather operations.

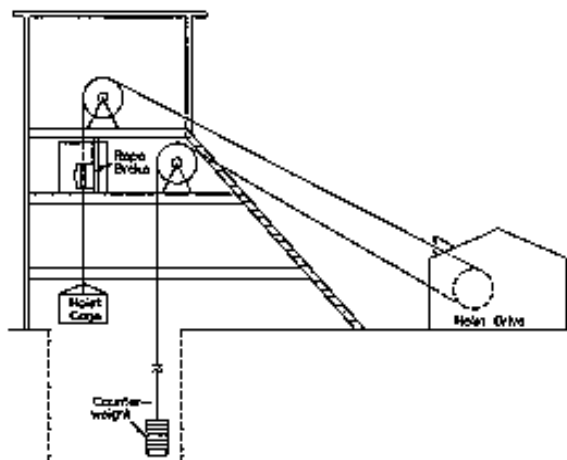


Fig. 1: Rope Brake Installation

Rope Brake Modifications

The mechanical design of the rope brake was modified for this application to a single hoist rope in addition to the modifications previously presented [6]. The rope pulse tachometer wheel was increased to approximately 5 inches in diameter which is more than double the original diameter. Consequently, the number of screws on the wheel was increased to maintain the original sensitivity of the speed and position sensing logic. The pulse tachometer wheel diameter was increased to provide a smoother operation on the relatively rough surface of the hoist rope, compared to a typical elevator rope.

A suspension rope guide, shown at the top of Fig. 2, was added above the rope pulse tachometer to prevent the slack rope from damaging the rope tachometer. Slack rope is generated by the two month safety catch test, required by Mine Safety and Health Administration regulations contained in the Code of Federal Regulations, Title 30 §75.1400.



Fig. 2: Rope Brake, Top View

The thickness of each rope brake lining was also increased from 3/8 inch for typical elevator installations, to 3/4 inch for this hoist installation. The increased thickness of the brake lining material was required to allow for the greater wear demand due to the additional rope abrasion, limited contact area on the single rope, and increased conveyance load. The additional brake lining also reduces the possibility of the 1-1/2 inch hoist suspension rope becoming damaged if the brake lining wears completely down to the brake pad mounting plates, since the combined thickness of the two linings is 1-1/2 inches. The brake lining wear characteristics will be discussed later.

The final modification was the addition of the brake pad guide shown in Fig. 3. The “L” shaped, pivoting steel plates on each side of the rope brake insures the brake pads remained parallel to each other. This prevents the original guides from binding or the brake piston from seizing when the brake is applied to the single suspension rope which is not directly in the center line of the rope brake.

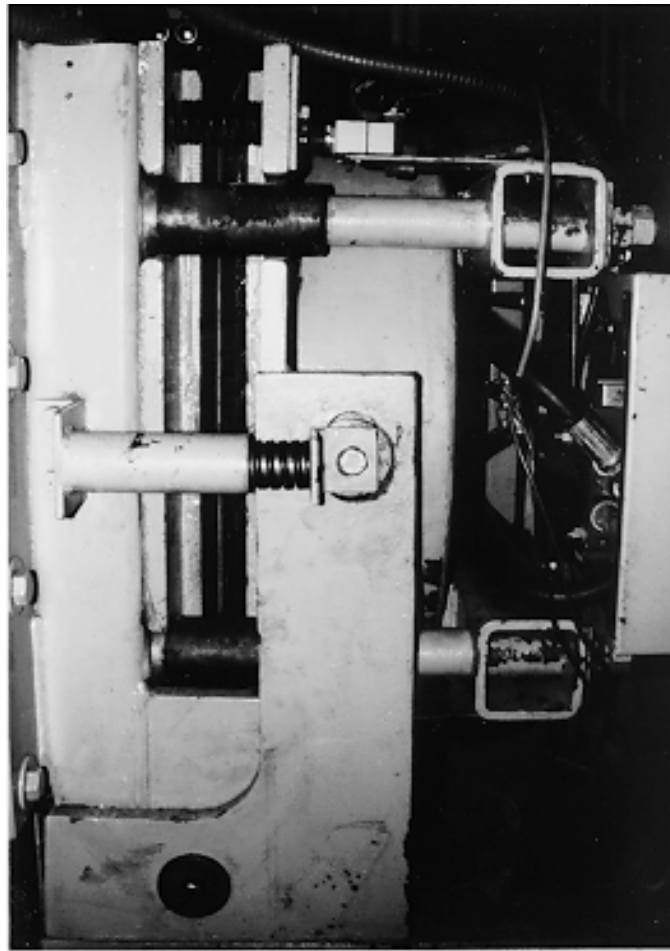


Fig. 3: Rope Brake, Side View

Rope Brake Tests and Results

The integrity of the existing hoist safety system was verified prior to performing any rope brake tests. The hoist emergency stopping, safety catches, overspeed and overtravel protection were dynamically tested. This procedure was essential to assure the safe completion of the rope brake test agenda.

A series of tests were then conducted to evaluate the performance of the rope brake under extreme loading conditions and multiple control system faults. The compound braking effect on the deceleration rate was also evaluated. Compound braking occurs when the rope brake and the hoist brake operate simultaneously.

Average Hoist Deceleration Rates: The rope brake and the compound braking deceleration rates are shown in Table I. The four test conditions represent the extreme hoist loading conditions for all possible directions of travel. The braking systems were activated at the rated speed of 600 ft/min. The average deceleration rates include the inherent mechanical time delay of approximately 300 msec before braking effort is realized. During this time period, the overhauling load begins to accelerate if it is traveling in the downward direction.

TABLE I

Average Brake Deceleration Rates

Cage Load (lb.)	Cage Direction	Rope Brake Deceleration (ft/s ²)	Compound Braking Deceleration (ft/s ²)
Empty	Up	3.2	8.0
Empty	Down	4.0	8.7
10,750	Up	5.3	9.5
10,750	Down	1.7	5.9

The deceleration rates of each braking system can not be added algebraically to yield the compound deceleration rate because of the mechanical time delay and the non-linear characteristics of the rope brake deceleration. For example, the machine brake will stop the empty cage traveling down at an average deceleration rate of 7.3 ft/s². Table I shows the rope brake only deceleration under this condition if 4.0 ft/s². However, the compound braking deceleration rate is 8.7 ft/s², not 11.3 ft/s².

The accepted maximum value for emergency deceleration is 16.1 ft/s² (0.5g). Limiting emergency decelerations to rates less than 0.5g will minimize the possibility of injuring the passengers on the hoist. As shown in Table I, the compound braking effort did not exceed 16.1 ft/s² (0.5g) for any possible condition.

Typical Test Recording: Fig. 4 shows the thermal array chart recording when the rope brake was applied, while the mechanical brake was held off. The cage was empty and was traveling at the rated speed of 600 ft/min, in the ascending direction.

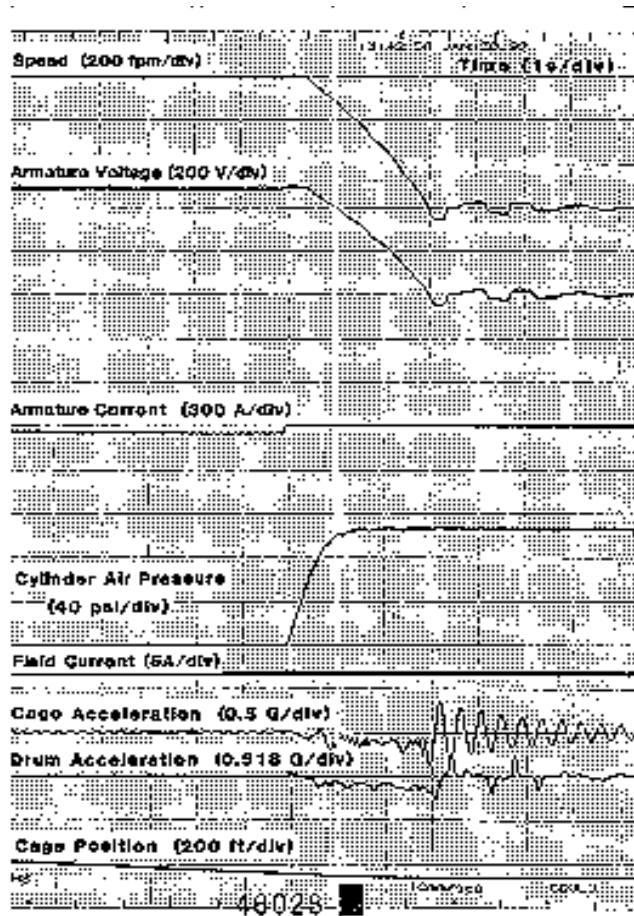


Fig. 4: Chart Recording from Rope Brake Test; Empty Cage, Ascending Direction, Rated Speed

The hoist speed and armature voltage signal demonstrate the initial acceleration that typically occurs when the armature current is interrupted before the rope brake develops sufficient braking effort to decelerate the falling counterweight. The speed deceleration profile shows the applied rope braking force is inversely related to the speed of the hoist. This observation is consistent with previously reported findings on multiple rope elevators [6].

The pressure in the rope brake cylinder increased logarithmically with a time constant of 550 milliseconds. The pneumatic time constant is affected by the inner diameter and total length of the air supply line. This may be a factor responsible for the inverse speed profile curve.

The oscillation in the cage acceleration signal typically occurs when the rope brake stops the hoist. The oscillations are attributed to the elasticity of the suspension rope. The oscillations are also

reflected into the hoist drum as shown by the drum acceleration signal. The inverse speed braking effort is indicated by the increasing deceleration shown in the drum acceleration signal.

Rope Brake Hold Test: A one-hour rope brake hold test was conducted to evaluate the static braking capacity and verify the integrity of the pneumatic system. The system was conducted by first setting the rope brake while the hoist was stationary with 125% of rated load (13,437 lb.) on the cage. Then the air pressure in the compressor tank was completely discharged. The rope brake remained set due to a check valve in the air supply line. The rope brake must hold the load for one hour with no more than a 1 percent air pressure drop in the rope brake cylinder.

A pressure correction factor was derived from the gas laws to allow for pressure changes due to ambient temperature variations during the one-hour test period. The pressure correction factor is; $P_1/P_2 = T_1/T_2$ or % Δ pressure = % Δ temperature (degrees Kelvin). An approximation for typical ambient air temperatures is; a 1 percent change in air pressure (psi) is caused by 5 degrees Fahrenheit change in air temperature (1 % Δ psi/ Δ 5°F).

Slack rope was generated above the cage by operating the hoist in the down direction with the rope brake set. The rope brake held the static overload (28,692 lb.) for one hour. During that time, the rope brake cylinder air pressure dropped from 104 to 103 psi.

The force applied by the rope brake at 103 psi is 42,164 lb. This easily held the static load of 28,692 lb. The rope brake should be able to hold the static load with only 70 psi of cylinder air pressure.

During emergency situations, the rope brake will only be required to hold the difference in weight between the cage load and counterweight if the hoist brake should fail. The greatest imbalance is 6,500 lb. when the cage is loaded with 10,750 lb.

Rope Brake Overspeed Tests: The most demanding test on the agenda was the overspeed activation of the rope brake at rated cage load (10,750 lb.) in the descending direction. The hoist speed was increased gradually until the rope brake sensed the overspeed and activated the rope brake at 702 ft/min. The hoist accelerated to 790 ft/min. before the rope brake began to develop braking effort. The hoist began to decelerate at a rate of 1.8 ft/s². When the hoist slowed down to 280 ft/min., the brake lining had worn completely away and the brake pads made contact. Without the braking effort, the hoist began to accelerate until the hoist brake was set at 750 ft/min.

The brake linings were replaced with a different material and the test was repeated on February 3, 1992. The hoist stopping distance was 75 ft. with an average deceleration of 1.1 ft/s². However, about 90 percent of brake lining material was worn away by the test. The replacement brake lining material may not have provided the same wear characteristics as the original material.

Rope Brake Lining Wear: The testing sequence called for the four empty cage tests in Table I to be performed followed by the remaining four rated load (10,750 lb.) tests. After the four empty cage tests were performed, a total of 0.5 inch of the brake lining material had been worn away. The remaining four load tests wore away 0.344 inch. (The rope brake only test, 10,750 lb., down, 600

ft/min. accounted for 0.281 inch of brake wear.) The remaining 0.656 inch of brake lining material was insufficient for the rated load, overspeed test. Therefore, the initial speed of the hoist when the rope brake is activated has a pronounced effect on the rope brake lining wear. This may be attributed in part to the inverse speed braking effort observed in Fig. 4.

Rope Lubrication: Since this hoist is not friction driven, the suspension rope can be protected by applying lubrication without causing rope slippage on the hoist drum. The lubrication presents a technical challenge not previously encountered when the rope brake was installed on friction driven elevators. The rope lubricant may have increased the stopping distances, which resulted in additional heat generation as the rope pulled through the set rope brake.

Test Summary

The Pennsylvania Bureau of Deep Mine Safety denied approval of the rope brake installed on the mine hoist pending modifications designed to reduce the brake lining wear. The decision was based on acceptance criteria established on previous rope brake installations.

CONCLUSIONS

Mining industry accidents, indicate a strong need for supplemental ascending overspeed protection on personnel hoisting systems. Auxiliary braking systems for mine hoists present difficult technical challenges that must be overcome to provide the needed protection.

Future rope brake design enhancements are expected to address the problems associated with its application to mine hoists. Increasing the brake lining path will improve the wear characteristics. This may also reduce the peak rope temperature generated when the rope brake is applied by distributing the frictional heat over a larger area. This rope brake design may also be applicable on draglines, shovels, cranes, and other single rope equipment.

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