SPEED AND POSITION SENSORS FOR MINE HOISTS AND ELEVATORS

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Abstract--**Mine hoist and elevator safety devices are tested periodically. However, periodic testing cannot ensure that a recently tested safety device will function properly when called upon. Ideally, the condition of critical safety devices should be continuously monitored but this is either impractical or impossible. The U.S. Bureau of Mines is conducting research on the more practical approach of continuously monitoring the speed and position of the shaft conveyance. By monitoring the depth and speed of a conveyance and comparing the result with the appropriate speed curve, an operator can be warned before the curve is exceeded and may then take appropriate action. This information will also detect other hoisting malfunctions such as motor or brake problems. Monitoring the actual cage position during operation and comparing this with the position indicated by the winding drum will indirectly enable the detection of rope slip for friction hoists and slack rope in drum hoists.**

Hoist systems presently in use are typically not equipped with appropriate devices for directly monitoring actual cage speed and position. Conventional overspeed protection for a mine elevator is currently done by a centrifugal governor. However, a mechanical governor is not capable of determining if the speed curve is changing with respect to the cage position in the hoisting cycle. Therefore, another means of sensing cage speed is needed.

This paper discusses several types of speed and position sensors, and advantages and disadvantages of each. The research suggests methods to monitor actual speed and position of the cage, which can be very significant in preventing overspeed accidents resulting from safety device failures in mine hoists and elevators.

I. BACKGROUND

In the United States, Mine Safety and Health Administration (MSHA) regulations require hoist/elevator systems for underground metal/nonmetal (MNM) and coal mines to be equipped with mechanical and electrical safety devices. These safety devices include overwind, underwind, slack hoist rope, tread wear, brake-clutch interlock, jammed conveyance detectors, track limit switches, over-temperature switches on bearings, ventilation switches, safety gate, safety chain, catches, and overspeed devices. The MSHA regulations specify daily, weekly, monthly, and annual inspections by the owner of the conveyance. The results from these inspections are documented in records and equipment logs. In addition to the testing done by the operator, MSHA also examines the safety devices and operational equipment periodically. However, periodic testing cannot ensure that a recently tested safety device will function properly when called upon.

Despite this testing, documented mine hoist/elevator accidents [1] have occurred resulting from electrical, mechanical, and structural failures. For example, shaft accidents associated with the hoisting cycle often occur when the conveyance is empty or lightly loaded. Survey data indicate that the car is empty or lightly loaded in 90% of the hoisting cycles [2]. This creates a situation where the counterweight is heavier than the car. If the brake fails, the car accelerates in the upward direction and crashes into the headframe resulting in an "overspeed" and/or "overwind" condition. Two well documented accidents that occurred in the United States [3,4], fit the above criteria; fortunately, the cage was empty in both accidents. These near misses could have easily been as disastrous as the accident at the Markham Colliery in the United Kingdom on July 30, 1973 [5]. A mechanical brake did not engage on a hoist, resulting in 18 men killed and 11 others seriously injured. Because of this accident, the United Kingdom adopted regulations governing cage position and overwind and overspeed monitoring for mine hoists.

The United States has 285 coal mines that utilize 218 hoists and 204 elevators. Of these 285 mines, 4% reported a total of 103 hoist and elevator accidents in 1992. An analysis of these accidents shows 77% were caused by faulty equipment and/or poor maintenance, and 43% of those were due to electrical problems such as defective relays, switches, fuses, and rectifier and motor failures. This continues to be the trend for hoist and elevator accidents over the past several years for both MNM and coal mines.

The United States also has 116 MNM mines with 310 hoists in service. From these 116 mines, 13% reported a total of 80 hoisting accidents in 1992. An analysis of these accidents shows 62.5% were caused by faulty equipment or poor maintenance, and 72% of those were due to electrical problems such as overtravel and overspeed switch failures, and failing motors, relays, and wiring. Further assessment of accident statistics shows that about 10% of all injuries in MNM mines in the period 1985-1992 were related to mine shafts, and that in 1992, almost one-half of all shaft accidents were in MNM mines. More than 90% of these were related to errors by operating and maintenance personnel. Therefore, research to improve and increase informational flow about operational status and relocating personnel from the hoisting function, are crucial. These data indicate that much of the Nation's existing mine hoisting infrastructure is not capable of continuing to function in a safe and economical manner without supplementing it with new technology.

II. APPROACH

Since continuously monitoring the condition of safety devices is impractical and/or impossible, a more practical approach of continuously monitoring the speed and position of the cage is being researched by the USBM. By comparing the result of monitoring the depth and speed of the hoist with the appropriate speed curve, the operator can be warned of excessive speed before the curve is exceeded, and appropriate corrective action can be taken. In addition, the information can be useful in detecting motor or brake problems and rope slip for friction hoists and slack rope in drum hoists can also be detected by comparing the actual cage position during operation with the position indicated by the hoist sheave or drum.

Current hoist systems are not equipped with appropriate devices for monitoring actual cage speed and position. Overspeed protection for a mine elevator is done by a centrigual governor, but a mechanical governor is not capable of determining when the speed curve is changing with respect to the cage position in the hoisting cycle. Therefore, some other means of sensing cage speed is needed.

III. EVALUATION OF SENSORS

Eight practical sensing techniques for monitoring the cage position or velocity were evaluated. These eight sensor techniques are: DC tachometer, optical encoder, toothed wheel detector, photoelectric position sensor, accelerometer, ultrasonic, microwave, and magnetic striping.

A. DC Tachometer

This sensor consists of a wound armature and a permanent magnetic stator with a set of commutator brushes. Rotation of the armature induces a voltage in the armature windings as they move through the field created by the permanent magnets. An output voltage is produced at the brushes which is directly proportional to the rotational speed of the armature. Because the DC tachometer has to be physically attached to a rotating part in the winding system, the system would have to be permanently modified to do continuous speed monitoring. This modification would be located either at the drum or sheave. Therefore, this would not give actual cage speed, but the rotation speed of the winding drum or hoist motor.

B. Optical Encoder

In this technique, an encoder, usually in the form of a slotted disk, is attached to a rotating part. As the encoder rotates, a beam of light is broken generating a pulse train. The train of pulses are counted during a fixed period of time by a pulse accumulator. By knowing the number of slots in the disk, the speed of rotation of the slotted disk and, thus, the speed of the rotating part can be determined. Because the slotted disk has to be physically coupled to the rotating part, the technique has the same limitations as the DC tachometer.

C. Toothed Wheel Detector

A toothed wheel is fitted to the drum shaft. Two proximity sensors installed close to the teeth generate pulses each time a tooth passes. This device is able to detect speed, distance, and direction. However, the speed is not true cage speed because the toothed wheel is mounted to the drum. Because it has to be physically coupled to the drum, the system would have to be permanently modified in order to do continuous speed monitoring.

D. Photoelectric Position Sensor

In this technique, a source of light is positioned on the cage. Sensors are positioned along the shaft wall. As the cage passes, each sensor detects the beam of light and thus records the position of the cage. The sensors can be used to measure speed with appropriate signal processing by measuring the time the cage takes to travel between two consecutive sensors. But this restricts the measurement to a specific location. Multiple sensors would be needed to measure velocity over the length of the shaft. This technique is relatively expensive because of the number of sensors required to obtain adequate resolution. A further limitation is that the operation is limited in a dirty, dusty environment which is typical in mining.

E. Accelerometers

These devices are normally constructed from piezoelectric materials such as quartz or ceramic crystals. The accelerometer would be rigidly attached to the top of the cage. When the cage changes speed, a stress in the crystal is produced by the force over the cross sectional area of the crystal. This stress results in a minute deformation of the crystal lattice. This deformation causes an electrical polarization in the crystal and a voltage is produced across the crystal proportional to the acceleration of the cage. In order to determine velocity, this voltage must be integrated. The system works well as long as there is a change in speed of the cage. Once zero acceleration is reached, it is difficult to determine an accurate velocity due to drifts in the electronic circuitry.

F. Ultrasonic

This is a self-contained unit equipped with a transmitter and receiver designed to operate at 62.5 kHz. It can be easily mounted on the cage so that the transmitted high frequency sound wave can be reflected off the shaft wall. When the reflected energy returns to the receiver, it is mixed with a portion of the transmitted signal. With appropriate signal processing, the velocity of the cage relative to the shaft wall can be determined. The main advantage of the unit is that it is a noncontact system. However, preliminary results indicate that the device is not reliable due to high-frequency noises generated in the mining environment.

G. Microwave

This is a self-contained unit equipped with a transmitter and receiver designed to operate at 24.125 GHz. It can be easily mounted on the cage so that the transmitted high-frequency wave can be reflected off the shaft wall. When the reflected energy returns to the receiver, it is mixed with a portion of the transmitted signal. With appropriate signal processing, the velocity of the cage relative to the shaft wall can be determined. Preliminary results show this unit to be the most promising because it is noncontact, rugged, environmentally insensitive to mining conditions, and relatively inexpensive.

H. Magnetic Striping

This technique involves magnetic striping of the hoist or guide ropes at intervals of four times the rope diameter. A noncontact magnetic sensor is used to detect the evenly spaced magnetic poles and the results are used to deduce the direction of travel. The technique then is to count the number of magnetic marks transversed in a given time period. For friction hoists only one hoist rope is striped. With the drum hoist, the guide rope is striped. Otherwise, a separate one-inch-diameter steel rope must be dropped and then striped. Usually, a fluxgate magnetometer is used to generate a pulse each time the magnetic stripe passes its head. This is a noncontact system that measures actual cage position and true rope speed. It can also be used to easily derive slack or taut rope conditions in drum hoist systems and slip detection in friction hoists. This is a proven technology which is being used in the United Kingdom, France, and Sweden. However, its initial setup cost is relatively expensive.

IV. CONCLUSIONS

Our evaluations indicate that the DC tachometer, optical encoder, and toothed-wheel detector will not give true cage speed because of the location of the sensors. The photoelectric position sensor, although it will give true cage speed, appears to be inadequate because of the dirty, dusty environment that is typical of mining. The ultrasonic system had several advantages in that it gave true cage position, was noncontact, portable, and rugged. However, this system is not reliable due to mine environment noise in its working frequency range. Accelerometers will measure cage velocity with appropriate signal processing. This technique appears to be promising. However, further work needs to be done in order to eliminate the problems associated with the drift in the signal processing. Magnetic striping has many advantages. It is a noncontact system that can be used to measure actual cage position and true rope speed. This is a proven technology which is being applied in United Kingdom, France, and Sweden. The major disadvantage appears to be the cost of the initial setup. A microwave velocity sensor has many advantages. It is noncontact, rugged, measures true cage velocity, cage direction, is environmentally insensitive to mining conditions, is intrinsically safe, and is relatively inexpensive. Preliminary results show this technique to be promising. However, more field work needs to be performed.

REFERENCES

[1] MSHA Health & Safety Analysis Center, ADA (Accident Data Analysis) "Shaft Accidents in Metal/Nonmetal Mines", 1989, 3 pp.

[2] Nederbragt, J. A. "Uncontrolled Speed, Up and Down", Elevator World, July 1989, pp. 56-60.

[3] Helfrich, W. J. "Island Creek Coal Company V.P.-5 Mine. MSHA" Mine Electrical Systems Division Report No. C-080978, August 1978, 8 pp.

[4] Barkand, T. D. "Investigation of the Accident and Installation and Testing of Dynamic Braking on the Main Elevator at Duquesne Light, Warwick Mine, 33 North Portal. MSHA." Mine Electrical Systems Division Investigative Report No. C-052287-12, May 1987, 27 pp.

[5] Loynes, E. "Safe Manriding in Mines," Mining Technology, December 1976, v. 58, No. 674, pp. 503-505, 507-509.