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Design and development of an electric winch for the extraction of vagonetes in a carbon underground mine

Diseño y desarrollo de un malacate eléctrico para extracción de vagonetas en una mina subterránea de carbón

Andrés L. Paez
Universidad Distrital Francisco José de Caldas
alpaez@correo.udistrital.edu.co

David A. Gómez S.
Universidad Distrital Francisco José de Caldas
daagomezs@correo.udistrital.edu.co

On this paper, the design of an electric winch to be used in an underground coal mine is shown. The design includes as background current mining methods, in order to compare their advantages and disadvantages. The formulation of the solution starts from the free body diagram of a full load wagon at the deepest point of the mine, from there, the forces acting on it are identified, and the tension is calculated in the steel cable. The design also includes the required protection and the control circuit for the motor starter. Under real operation in mine, we check the correct operation and performance of the prototype, fully being satisfied customer's need. In addition, the objectives were met 100%, fully meeting the proposed schedule.

Keywords: Electric winch, free body diagram, inclined plane, mining extraction

Éste artículo muestra el diseño de un malacate eléctrico para ser utilizado en una mina subterránea de carbón. El diseño contempla como antecedente los métodos actuales de extracción minera, a fin de comparar sus ventajas y desventajas. La formulación de la solución parte del diagrama de cuerpo libre de un vagón a plena carga en el punto más profundo de la mina, a partir de allí se identifican las fuerzas que actúan sobre éste, y se calcula la tensión en el cable de acero. El diseño contempla también las protecciones requeridas y el circuito de control para el arrancador del motor. Bajo operación real en una mina, se comprobó el correcto funcionamiento y desempeño del prototipo, satisfaciéndose completamente la necesidad del cliente.

Palabras clave: Diagrama cuerpo libre, extracción minera, malacate eléctrico, plano inclinado

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Introduction

Coal is a globally used energy resource. It is widely used for electricity generation, in the steel industry, and can be transformed into a crude oil similar to oil. Colombia has eight percent of the total percentage of the world in terms of coal deposits, extracted in large and small scale mining (Mejía, 2005).

Mineral deposits have been formed on land for millions of years under special conditions, mineral deposits are rare and are generally linked to anomalous geological structures (Bustillo & López, 1996).

Mining materials are non-renewable resources, which is why mining is an activity that must be managed responsibly in order to make the most of these limited resources (Hernández, Pedraza, & Martínez, 2016). Mining companies aim to achieve optimal extraction of mineral reserves with the greatest economic benefit and security of operations (Oyarzun & Oyarzun, 2011).

Depending on where the mineral deposits arise, different mining methods are used. Certain deposits are obtained in surface mines or open-cast mining, others with underground excavations that are accessed through tunnels (Virigilio, 2007).

The underground mining method is used when deposits are narrow, deep and covered with quantities of sterile material that make open pit mining economically unviable (Herrera & Gómez, 2007). Its method is based on building tunnels or galleries, to access the mineralized zones and result in the formation of a network of underground levels for production and transport from the interior of the mine to the plant, usually located on the surface (Herrera & Gómez, 2007).

To avoid landslides, the walls and the roof of the tunnel are stabilized, using an appropriate fortification for each type of terrain, which depends on the characteristics of this and the use it will be given. The classification of this type of mining is small, medium or large according to its annual production as follows:

- Metals and precious stones:
  - Small-scale mining up to 250,000 m^3/year.
  - Medium mining, between 250,000 and 1'500,000 m^3/year.
  - Large-scale mining, greater than 1'500.000 m^3/year.
- Coal:
  - Small-scale mining, up to 180,000 m^3 or 24,000 ton/year.
  - Medium mining, between 180,000 and 6'000,000 m^3 or between 24,000 and 800,000 ton/year.
  - Large-scale mining, greater than 6'000.000 m^3 or 800.000 ton/year.
- Other (excludes construction materials):
  - Small-scale mining, up to 100,000 tons/year (Muñoz, 2002).

For many countries, their economic base is focused on small-scale mining because of the low cost of labor and materials (Avila, 2000).

With transport in underground mining, the aim is to move the extracted ore to the outside of the mine. In old mining, the transport system used was baskets transported by people. Then the wheelbarrows were used. Later, in order to facilitate the rolling of these forklifts, aligned and leveled boards were installed, which can be considered as the beginning of the rails.

With the creation of metal rails and eyelash wheels and the use of animal power, greater loads could be moved with less effort. The use of cattle (horses, mules or oxen) was frequent, but teenagers or young children also worked on these tasks.

Gradually, the transport was mechanized, incorporating the technology developed with the arrival of the industrial era. Thus, the internal combustion locomotive and the electric locomotive made it possible to move ever-increasing weights, unthinkable with animal power (Sandoval, 2010).

In small-scale mining, the transport of mining material is done by means of winches, it is a rotating mechanical system, driven manually or by an engine that is used to drag, lift or move large loads such as minerals (ore, rock, coal, and others), personnel, tools, and supplies. It consists of a drum in which the steel cable is wound to which the means of transport is connected.

The use of conveyor belts is not suitable for this type of mining because of the angles of inclination at which it works. The maximum angles for optimum operation of a conveyor belt system are 25 degrees. Its main use is the transport of minerals into underground mines and not the extraction out of it.

Different techniques are used to extract coal in small-scale mines, ranging from human power (for very small loads) to internal combustion engines, which become unsafe and dangerous forms for both workers and the ecosystem.

This project seeks to technify the extraction of minerals in small-scale mines. The project is carried out for an underground coal mine in the municipality of Samacá, Boyacá (Colombia). We implemented an electric winch prototype for the extraction of the wagons (Martínez, Montiel, & Valderrama, 2016).

Problem formulation

Coal extraction at the Cochinillos mine

Samacá is a municipality located in the center of the department of Boyacá. The main economic activities of the municipality are agriculture, farming, and mining.

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The mining works have as main activity the underground exploitation of coal.

The Cochinillos coal mine is a one-man coal extraction company, located in the mining area of the municipality of Samacá, in the village of La Chorrera. The exploitation of the deposit is made in the subsoil, using the method of underground extraction or undermining, because the veins are narrow, deep and are covered with large quantities of sterile material. Company information is given in table 1.

Table 1
Technical data Cochinillos mine.

NIT	4.233.843
Exploitation license	LGD-14511 (31/072005)
Location	Vereda la Chorrera, municipality of Samacá, Boyacá (Colombia)
Economic activity	Coal Deposit Exploitation
Number of mine mouths	2
Monthly production	Approximately 336 tons
Daily production	Between 11 and 13 tons per mine mouth

Access to the coal seams is through tunnels that allow the transit of light wagons (Montiel, Jacinto, & Martínez, 2015). The ore is removed manually by drilling, using mechanical and pneumatic tools. The extraction of the mining material to the outside of the mine is carried out with wagons with a capacity of 1 ton coupled to a winch by means of a steel cable. Table 2 describes the extraction process of a coal mine.

The Cochinillos coal mine has two mine mouths, in which the main activities of the mining personnel are the chopping of coal, structural reinforcements, boat and transport of the mining material (Sandoval, 2010).

The mine has two mine mouths. The tunnels have a height of 1.8 m, a width of 1.7 m and distances between supports of 1 m. According to the norm, the minimum free area of a mining excavation must be three square meters with a minimum height of one meter and eighty centimeters (Díaz, 2015).

For mine two, where the project was developed, the slope angle is 35 degrees (in the worst case) and the length of the main slope is 100 m.

Table 2
Coal extraction process at the Cochinillos mine.

Process	Description
Preparation of the work site	Ventilation to the mine by means of a ventilation circuit. With a gas measuring instrument (Ventis MX4), the working atmosphere is verified by checking that it is within the permitted limits (Sandoval, 2010). The gases to be controlled are Methane (CH4), Oxygen (O2), Carbon Monoxide (CO) and Hydrogen Sulphide (H2S).
Entering the mine	Staff walk in to the extraction site with all PPE for the activities to be performed.
Chopped	Chopping is carried out for the extraction of coal and rock manually (picks and shovels or with pneumatic hammers).
Support and maintenance of the mine mouth	The internal structure of the mine is supported with wooden doors to avoid collapses by internal pressure of the rocky massif. For the reinforcements is used wood of an approximate thickness of 20 cm and a height of 2 m.
Coal selection and sterile disposal	During the filling of the wagon a selection is made between coal and rock in order to avoid impurities. The rock is extracted from the interior of the mine in the same way as the coal and is gathered in the courtyard of the bocamina or placed in unattended work inside the mine.
Transport of the wagon into and out of the mine	For transport into the mine, the wagon coupled to the winch by means of a steel cable is lowered for transporting tools and supports. Inside the mine, the wagon filled with mining material is extracted to the surface. The interaction between the miner and the winch operator is done by means of a cytophone for communication related to the advance or stop of the wagon.
Transport and unloading of coal into the hopper	Already the wagon with mining material out of the mine, is dragged to the hopper where the coal is collected waiting to complete the loading of a dump truck between 11 and 13 tons of coal.
Load	The hopper load is emptied into a dump truck.
Transportation to sales site	When the dump truck is loaded it goes to the point of sale. In this place it is weighed and its quality of coal is determined, fixing with it the selling price.

Underground mining technologies

Manual mechanical winch. Use animal or human force to spin the drum that winds the steel cable. Material extraction times are long but discontinuous, so their use is limited to a few hours in the extraction time in the mine.

They are useful when the material to be extracted is very light and the drag does not exceed certain distance limits

(Fig. 1). Table 3 shows the main characteristics of a manual winch.

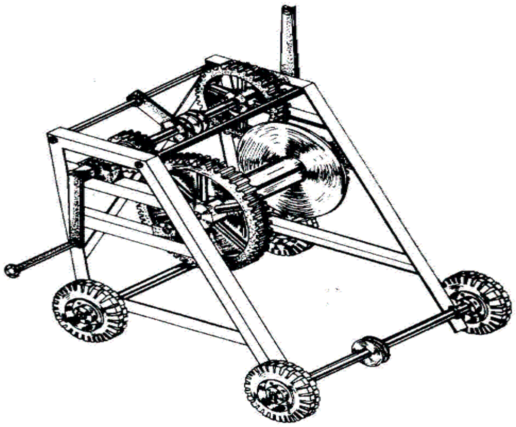

Figure 1. Manual mechanical winch (Ramos, 2004).

Table 3
Features of a manual winch.

Manual mechanical winch	
Application	Lifting and/or dragging of load
Capacity	5000 kg
Length	200 m
Transmission	Crown Endless
Lifting Speed	3 m/min
Drag time	33 min, to 100 m

Internal combustion winch. It is driven by an internal combustion engine that turns the mechanical system in charge of winding the steel cable coupled to the load. In small-scale mining this type of winches are built in an artisanal way, complete automobiles are used (Fig. 2), or sometimes the engine is removed to be adapted to a drum for spinning (Fig. 3). This system was initially used in the intervened mine. A video with its operation can be seen on: http://youtu.be/Zdk7xA6QyuE.

The practical use of this class of engines is given by their simplicity in installation and because they have completed their life cycle in the cars in which they were operating.

The consumption of fossil fuels as a primary energy source and oils or greases to lubricate mechanical elements generate negative impacts on the environment. These engines have a high drag capacity and have a gearbox to control the ascent and descent of the wagons. Table 4 shows the main characteristics of the winches used in the Cochinillos mine for the extraction of wagons.

The maintenance of this technology and the consumption of resources to guarantee its operation are costly. The useful life of these engines is low, affecting many times in the production of the mines.

Figure 2. Diesel tractor used for wagon extraction in an underground coal mine.

Figure 3. Petrol engine used for car extraction in an underground coal mine.

Table 4
Characteristics of the combustion winches in the Cochinillos mine.

Internal combustion winch		
Application	Lifting and/or dragging of load	
Engine	Diesel	Petrol
Automotive	Nuffeleld 1954 tractor	Dodge 1500
Power	45 Hp	90 Hp
Transmission	Mechanical	Mechanical
Drag time	6 min, to 100 m	6 min, to 100 m

The Cochinillos mine operates with two internal combustion winches, one for each mine mouth. The average fuel consumption for the tractor in the use of mining tasks is 0.92 gal/day and that of the gasoline engine is 1.38 gal/day.

These depend on the operation of the mine and the daily production of coal or sterile.

Optimal operation of internal combustion winches requires preventive maintenance consisting of periodic oil changes, oil filters, and fuel filters.

Pneumatic winch. This device takes the power from a pneumatic head, which receives an air pressure, which is distributed alternately in its force plungers, generating a rotary power, which provides movement to the drum winding the cable, as well as consists of a braking band.

The pneumatic winches (Fig. 4) are ideal for use inside underground mines. They have a higher pulling force than other winches of the same size and because their energy source is air this helps the ventilation of the mines.

Figure 4. Pneumatic winch.

For optimum performance of pneumatic winches, they require preventive maintenance, which consists of general cleaning and verification of the level of lubricating oil in their mechanical parts. Table 5 shows the main characteristics of a pneumatic winch.

Table 5
Characteristics of Ingersoll Rand pneumatic winch.

Pneumatic winch	
Application	Lifting and/or dragging of load
Brand	Ingersoll Rand
Capacity	2000 kg
Lifting speed	25 m/min
Drag time	4 min, a 100 m
Air consumption	208 l/s
Pressure	0,6 - 0,8 Mpa
Power	16 Hp

Its installation is simple by means of hoses connected to an air compressor outside the mines, which can have electricity or diesel fuel as its main source of energy.

Compressors require preventive maintenance every 250 hours of work associated with oil change, oil filters, fuel filters, and compressor unit filters. Table 6 shows the main characteristics of the air compressor used in the Cochinillos mine for the operation of the tools (pneumatic hammers).

Table 6
Atlas Copco XAS 185 JD air compressor features.

Atlas Copco XAS 185 JD air compressor	
Air supply	151 - 185 l/s
Presión	0,7 - 1,4 Mpa
Power	49 Hp
Engine / John Deer	Diesel
Fuel consumption	1,2 gal/h, to full load

The air requirement of this tool is high, so it is necessary to have a large capacity compressor, which makes it difficult to apply in the small scale mine. Normally the air compressors drive hammers and pneumatic drills inside the mines with certain air consumptions, when connecting a pneumatic winch this consumes the air necessary for the operation of the other tools.

Electric winch. It uses the electrical energy in the motors to produce its mechanical energy in spinning the mechanical system in charge of winding the steel cable coupled to the load. There is a great variety of electric winches, single-phase and three-phase (Fig. 5). Magnetic brakes are added to these motors to keep the load in one position, in times when stops are made.

Figure 5. Electric winch with remote controls (Mattoli, n.d.).

They are ideal for outdoor use in underground mines, thanks to the few mechanical elements that compose them need little maintenance and do not generate carbon emissions that could enter the mine. Table 7 shows the main characteristics of an electric winch with a pulling capacity of 1.5 tons.

To make the most efficient use of electric motors, they are coupled to a speed reducer system to increase the necessary torque and decrease the power and size of the motors.

For the optimal functioning of the electric winches, the preventive maintenance that is carried out is general cleaning and verification of the level of the lubricating oil in its mechanical parts.

Table 7

Features of an electric winch.

Electric winch	
Application	Lifting and/or dragging of load
Capacity	1500 kg
Lift height	100 m
Lifting speed	22 m/min
Power	7,5 Hp
Brake	Electromagnetic discs
Voltage	208 V
Drag time	4 min, to 100 m
Electrical system	In metallic box with electrical circuit programmed with contactors and buttons for external control

Methodology and design

Calculation of stress

For the calculation of the stress to which the steel cable will be subjected, the wagon filled with coal at the deepest point of the inclined plane is considered, in order to consider the forces interacting on it (Fig. 6).

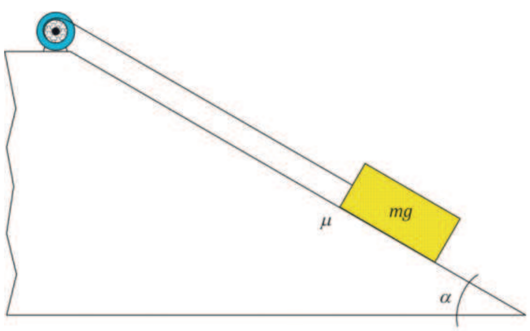

Figure 6. Inclined plane.

The forces acting on the fully loaded wagon at the incline of an underground mine are: the weight of the load, the weight of the cable at 100 m, the normal force of the load and the cable, the tension on the cable, the frictional force between the wheels of the wagon and the rail and the frictional force between the cable and the ground when pulled through the underground mine (Fig. 7).

The wagon (Fig. 8) is the means in which the mining material is transported, it is coupled with the winch by means of a steel cable. The one-ton wagon weighs 450 kgf, and we consider the weight of 100 m of cable.

$$W_V = m_V g = 1450\,kgf \tag{1}$$

$$G_S = 0,883\,\frac{kg}{m} \tag{2}$$

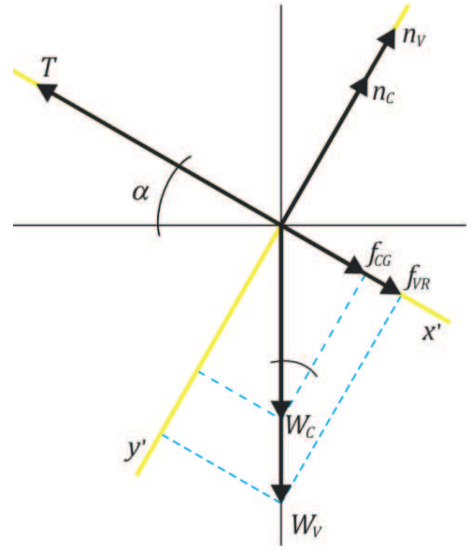

Figure 7. Free body diagram for wagon.

Figure 8. Mine wagon.

$$W_C = L \cdot G_S = 88,30\,kgf \tag{3}$$

The frictional forces interacting against movement occur by friction between the steel wheels and rails, and the steel wire rope dragged on the ground. To calculate the friction force between the steel wheels and the rails the coefficient obtained from Fig. 9, μ_1 = 0,2 at a speed of 0,06 km/h is used.

The coefficient μ_2 = 0,3 is selected to calculate the friction force of the steel wire rope dragged on the ground (Serway, 2003). In order to calculate the tension in the steel cable, the vectorial sum of all the forces interacting on the wagon is made.

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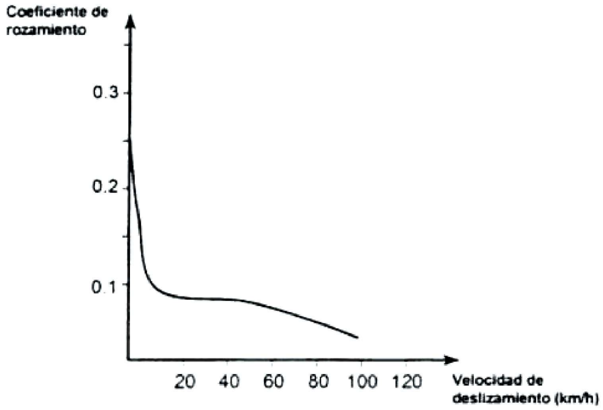

Figure 9. Average values of the coefficient of friction between steel wheel and rail (Álvarez & Luque, 2003).

$$\sum F_{x'} = T - W_V sin\,35° - f_{VR} - f_{CG} - W_C sin\,35° = 0 \quad (4)$$

$$\sum F_{x'} = T - W_V sin\,35° - \mu_1 W_V cos\,35° - \mu_2 W_C cos\,35° - W_C sin\,35° = 0 \quad (5)$$

$$T = W_V sin\,35° + \mu_1 W_V cos\,35° + \mu_2 W_C cos\,35° + W_C sin\,35° \quad (6)$$

$$T = 1128,26\,kgf = 11064,42\,N \quad (7)$$

Steel cable selection

A steel cable is a set of steel wires, stranded around a fiber core, which forms a metal rope suitable for resisting tensile stresses with appropriate flexibility qualities.

The steel cable connects the wagon with the motor reducer, this element must be able to support the total load. Its manufacture is under the following standards:

- American Petroleum Institute (A.P.I. Standard 9A)
- American Federal Specification (RR-W-410D)
- American Society For Testing & Materials (A.S.T.M.)
- British Standards Institute (B.S.)
- Deutsches Normenausschuss (D.I.N.)
- International Organization for Standardization (I.S.O.)

Serway (2003)

The following variables are taken into account for the proper selection of the cable:

Breaking load (resistance): Refers to the load that must be supported taking into account the static load, stop load, a sudden start. It is recommended to multiply the working load by a safety factor, indicated by the manufacturer.

Resistance to bending and vibration (fatigue): It happens when the cable is bent like in the pulleys. The lower the bending radius, the greater the fatigue action.

Abrasion resistance: It occurs when the cable rubs or is pulled against the ground and rollers.

Crushing resistance: The winding of the cable in several layers, on the drum.

Corrosion exposure: Because of the atmosphere, the cross-section decreases, the cables must be protected by periodic greasing (Ramos, 2004).

The cables used in mining operations are usually made of steel with breaking strength ranging from 140 to 180 kg/mm^2 (Ramos, 2004).

For cable selection, a safety factor is used taking into account the distance traveled (100 m) and the total load (W_V = 1450 kg). Table 8 presents the safety factors for steel ropes used in mining.

Table 8
Safety factors for steel cables used in mining operations (Icontec, 2004).

Depth [m]	Safety Coefficient	Replacement when it arrives
0-150	8	6,4
150-300	7	5,8
300-600	6	5,0
600-900	5	4,3
> 900	4	3,6

$$FS = \frac{True\ Resistance}{Required\ Resistance} \quad (8)$$

$$R_{True} = FS \cdot R_{Required} \quad (9)$$

Where *FS* is a safety factor for the weight to be supported by the cable (Fig. 10):

$$R_{True} = 2175\,kgf \quad (10)$$

The total load that the steel cable will support is:

$$T_r = T \cdot S = 2175 \cdot 8 = 17400\,kgf \quad (11)$$

Where:
- T: Total load or true resistance to which the cable is subjected.
- S: Safety coefficient.

Finally, the diameter of the drive cable is calculated:

$$d = k \cdot \sqrt{T} = 0,36 \cdot \sqrt{2175} = 15,85\,mm \quad (12)$$

Where k is the coefficient of rupture that is selected like this:

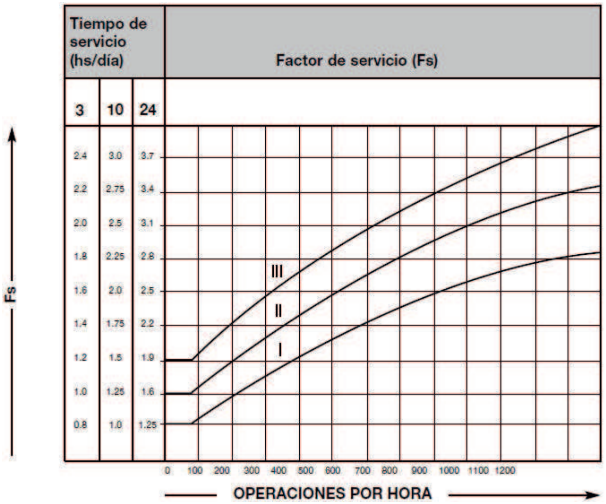

Figure 10. Safety factor (FS) (Emocables, 2013).

- 0,32-0,34 for the group I partial loads and frequent operation.
- 0,34-0,36 for the group II total loads and normal service.
- 0,36-0,38 for the group III total loads and frequent service.

According to these dimensions, the cable is chosen in agreement to the manufacturer and having the minimum breaking load (Icontec, 2004).

$$Breaking\ load = 17400\,kgf \cdot 9,8\,\frac{m}{s^2} = 170,52\,kgf \quad (13)$$

According to the manufacturer in Colombia, the cable selected was the steel cable with jute core, since it complies with the characteristics shown in table 9.

Table 9
Selected cable with manufacturer's data (Condori & Meléndez, 2015).

Diameter		**Minimum breaking load [kN]**	**Diameter range**	
[Inch]	[mm]		Min inch	Max inch
5/8	15,87	176	0,748	0,785

- Seale construction of 19 wires, more resistant to abrasion.
- Highly flexible fiber core with good tensile and compressive strength.
- Grease with very good adherence.

Other technical data that will help us in our calculations taken from the manufacturer:

- Approximate weight 0.883 kg/m.
- Minimum breaking load 150 kN, 167 kN.

Drum

In the drum the steel cable will be wound in an orderly manner, for which it must comply:

- Bending fatigue in a cable is an important variable and is related to the diameter of the drum.
- The diameter of the drum is calculated according to the characteristics of the cable.

$$D_T = s \cdot d \quad (14)$$

$$D_T = 16 \cdot 15,87 = 253,92\,mm \quad (15)$$

This value indicates the minimum diameter of the drum. The length of the drum is determined by defining a number of turns for the first layer, in this case, $L = 20$. The number of turns N is defined as:

$$D_T = 300\,mm \quad (16)$$

$$L = N \cdot \pi \cdot D_T \Rightarrow N = \frac{L}{\pi D_T} = 21 \quad (17)$$

For a cable diameter of d_c = 1,74 cm:

$$L_T = N \cdot d_c = 36,5\,m \approx 40\,m \quad (18)$$

The value is rounded to facilitate its construction. The weight of the cable for this amount of meters is important to establish the material of the drum and not suffer deformations during the time of operation. We established the following parameters:

$$W_C = Cable\ weight\left[\frac{kg}{m}\right] \cdot l_c \cdot g \quad (19)$$

Where:

- l_c: Total cable length.
- g: Gravity.

$$W_C = 840\,N \quad (20)$$

With a total of four turns, and the empty drum diameter plus 0,128 m (eight turns * 0,016) of cable accumulation, results in a full diameter of 0,428 m. Table 10 shows the length of cable wound over the drum per turn.

Table 10
Total cable wound on the drum.

1 turn	DT empty	21,67 m
2 turn	DT empty+0,032	23,98 m
3 turn	DT empty+0,064	26,30 m
4 turn	DT empty+0.128	30,95 m
Σ = 102,91 m		

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Gear motor

The gearbox is the mechanical equipment required to reduce motor speed to a safe level at working conditions, transferring power and amplifying effective torque to the load.

A gear motor is obtained by coupling an electric motor to the gear reducer which transmits the power of the motor to the driven machine complying with the principle of energy conservation, which tells us that the energy entering the system is equal to the energy leaving it plus the losses generated inside it.

In some cases, it is more important the moment of torsion that can give a reducer than the same power. The mechanical work that needs to be obtained is given by the torque.

For a proper selection, you must take into account the load to be moved, the torque required, the class of motor will carry the machine, and the speed of input and output of the reducer. For the tension in the drum, we define the torque in the gear motor shaft for a radius in the drum of 15 cm.

$$\tau = T \cdot r \ [Nm] = 11064,42 \cdot 0,15 = 1659,66\,Nm \quad (21)$$

The duty factor is a multiplier that indicates the degree of protection with which our speed reducer operates, it depends on the daily operating time and the type of service to which it will be subjected.

The mine has an eight-hour working day, seven days a week. With an average of six operations per hour of the winch and a class II load (Emocables, 2013), we selected a service factor of 1.25 (Fig. 10).

The required torque is defined as:

$$\tau_{Req} = \tau \cdot FS \ \ [Nm] = 1659,66 \cdot 0,25 = 2074,58\,Nm \quad (22)$$

Considering the synchronous speed of a four-pole motor and an efficiency of 91.7%, then:

$$v_{in} = \frac{120 \cdot f}{poles} = \frac{120 \cdot 60}{4} = 1800\,rpm \quad (23)$$

The output speed of the reducer with a ratio of 1:70 and an efficiency of 90.4% is:

$$v_{out} = \frac{v_{in}}{R} E_R = \frac{1800}{70} 0,904 = 23,24\,rpm \quad (24)$$

The efficiency of the gear motor is given by:

$$\eta = \frac{P_{out}}{P_{in}} \quad (25)$$

Pair on the shaft:

$$\tau_{Req} = \frac{P_{out}}{\omega_{s2}} \quad (26)$$

Input power:

$$P_{in} = \frac{P_{out}}{\eta} = \frac{\tau_{Req}\omega_{s2}}{\eta} = 5,51\,kw \quad (27)$$

$$P = 7,38\,Hp \quad (28)$$

Power and control circuits

In order to adequately protect this type of motor, adequate coordination of protections must be taken into account. Having determined all the components of the winch and knowing that the gear motor must comply with the operation of lifting, lowering and stopping the load, the force and control circuit is carried out according to the components available on the market. Complying with regulations, we carry out the following considerations:

Protection against fault current. This drift from the transformer or from the general board. It must be suitable protection that complies with the standard or according to the rating plate of these. They must be magnetic switches or fuses which are selected according to the manufacturer.

For magnetic type switches, they must comply with Table 430-151B of Locked Rotor. There are high currents approximately eight to 10 *In* of the motor, and it must not present a trigger by the presence of a short circuit, for that reason they lack thermal unit.

Overload protection. Thermal protection is implemented. This will be integrated to the motor or external to it. This one will present shot in presence of high currents in a short time, its action is almost instantaneous ("Motoreductores a sifín y corona", n.d.).

According to the motor nameplate:

- V_{in} = 208 V
- P_{in} = 7,5 [HP]

The current for selecting the appropriate protection is calculated as follows:

$$I_{in} = \frac{P\ [W]}{\sqrt{3}V_{in}} = 15,53\,A \quad (29)$$

By design we choose protection 1.25 times the nominal current, i.e. I_p = 19,41 A. We selected a magnetic switch with the following characteristics:

- Three-pole, moulded case, industrial type, 40 kA at 240 V, 36 kA at 400 V, fixed magnetic shot at 10 In, 20 A, Manufacturer: MEC.

We implement a direct starter with rotation inverter because it has a simple circuit for motor control, and we want to use easily accessible components.

Considering that the starting current of the motor varies from 5.6 to 8.4 *In*, the two types of starting are studied in order to choose the best option. For a direct start, the motor receives a direct voltage from the mains, which the starting torque is high and is used for motors starting with axle load. A reduced voltage start as its name suggests starts the motor at reduced voltage, the starting torque is reduced and is used for motors without a load on the rotor. With these considerations, we implement a direct starter with turn inverter (Fig. 11 and Fig. 12).

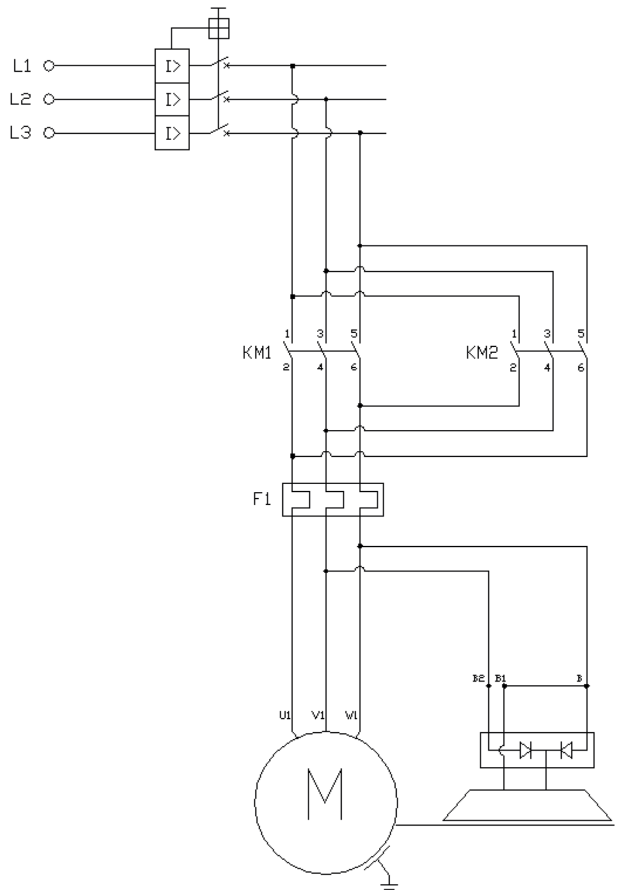

Figure 11. Force circuit.

This control board solution reduces peak currents at startup and mechanical wear of the drive.

The guidelines to follow after implementing this start is that the service transformer is sized for a start of these, the connection must be adequate to withstand the starting current, and have no voltage drop problems at the time of operation.

Economic evaluation

The implemented solution was analyzed from its costs assuming the direct purchase to the supplier and carrying out all the electrical assembly according to the unifilar by the designers. This included the delivery of plans and on-site tests (table 11).

The materials required were:

- A pulsating station.
- A three-pole magnetic switch.

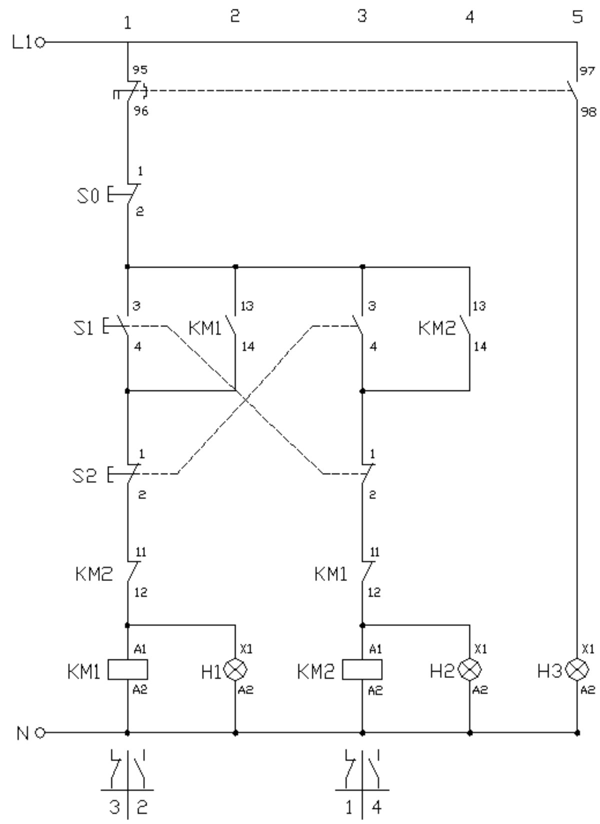

Figure 12. Control circuit.

- Screws, bolts, and anchoring elements (as appropriate according to the work panel to be used).
- One IP 55 mounting panel.
- Two three-pole contactors with one auxiliary normally open contact (NO) and one normally closed contact (NC).
- A thermal relay.
- Rubberized cable 3x12 AWG.

As the workshop is less than 15 m away, there is no need to implement protection inside the panel.

For the gear motor set the following selection was made: Gear motor with electromagnetic brake, consisting of a squirrel cage type motor and an electromagnetic brake, ideal for making an instant stop of rotation. The characteristics of the geared motor are shown in table 12.

Drum, roller and support structure. According to the calculations, weights, and stresses to which the winch was to be subjected, we designed the solution shown in Fig. 13. The layout of the final assembly is shown in Fig. 14. The final cost of the project is detailed in table 13.

As can be observed, the most representative part of the final cost of the project was the electrical part. It includes the costs of labor, tools, equipment, and material.

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Table 11
Supply, installation, and testing of electrical panel for control and force, of the electric winch.

I. Machinery and equipment				
Description		Rate/hour [COP]	Performance	Unit value [COP]
Electrician minor tools		$2,241	48.00	$107,580
Computer and office equipment		$833	24.00	$20,000
Truck		$15,000	18.00	$270,000
			Subtotal machinery and equipment:	$397,580
II. Materials				
Description	Units	Price per unit [COP]	Quantity	Unit value [COP]
Metal box IP55 1000x800x300 mm	Unit	$955,830	1.00	$955,830
Switch 18 A, 1NA+1NC 220 V T.M.	Unit	$180,315	2.00	$360,630
Thermal relay 9-14 A	Unit	$80,849	1.00	$80,849
Emergency pushbutton	Unit	$45,648	1.00	$45,648
Terminals, labels and ties	Unit	$1,218	10.00	$12,180
Station two pushbuttons green red	Unit	$72,728	1.00	$72,728
RETIE certification of the panel	Unit	$609,000	1.00	$609,000
Rubberized cable 3x12 AWG, 600 V, THW 75C	m	$5,664	10.00	$56,640
Nylon and security tapes	Unit	$1,523	10.00	$15,230
			Subtotal materials:	$2,208,735
III. Workforce				
Description		Rate/hour [COP]	Performance	Unit value [COP]
Technologist		$15,949	80.00	$1,275,948
Technical assistant		$6,844	40.00	$273,767
			Subtotal workforce:	$1,549,715
			Total Direct Cost:	$4,156,031

Table 12
Geared motor characteristics.

Reference: 1LE2221-2BC11-4AA3-Z				
Power	**Voltage**	**Speed**	**η**	**Weight**
7.5 Hp	230 V, 60 Hz (Standard)	25 rpm	0.917	262 kg

Finally, the winch installed using a set of worm gear motor and crown is shown in Fig. 15. A video showing the system in operation can be seen on: http://youtu.be/3MGqxiDfSkg

Findings

The cost of the gallon of gasoline and diesel in the municipality of Samacá (Boyacá) for the month of January 2014 is $8.585 and $8.556 respectively. The cost of kW/h for

Table 13
Final budget result.

Activity	Units	Price per unit [COP]	Quantity	Total value [COP]
Supply, installation, and testing of electrical panel for control and force of electric winch of 7.5 Hp include connection and other elements for installation and final testing.	Unit	$4,156,031	1.00	$4,156,031
Roller installation.	Unit	$181,318	5.00	$906,590
Supply and installation of support structure and drum.	Unit	$1,298,278	1.00	$1,298,278
Supply and installation of motor reducer Siemens.	Unit	$3,069,231	1.00	$3,069,231
Supply and installation of 5/8 jute core steel cable.	m	$5,400	100.00	$540,000
			Total Direct Cost:	$9,970,130

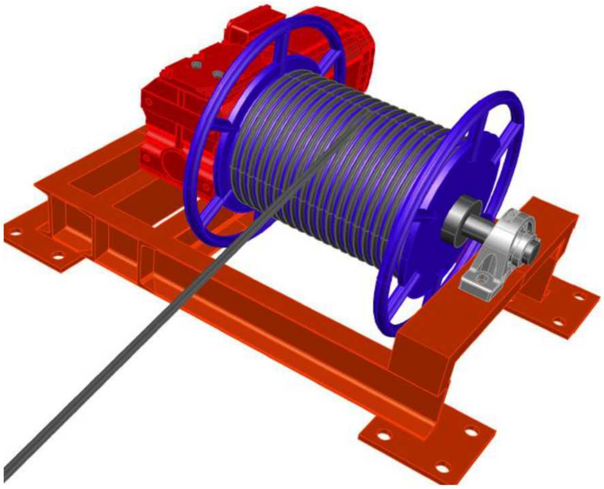

Figure 13. Solution designed for support structure and drum.

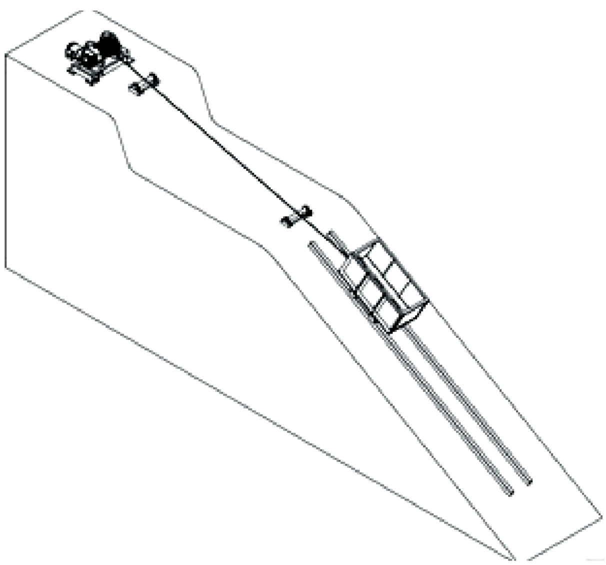

Figure 14. Final assembly.

Figure 15. Electric winch. Cochinillos mine location.

Table 14
Fuel consumption for the operation of the internal combustion winches in the Cochinillos mine.

1954 Nuffield Tractor		Dodge 1500	
Fuel consumption	Cost	Fuel consumption	Cost
22 gal/month	$ 188.936	33 gal/month	$ 284.361
5,5 gal/week	$ 47.234	8,25 gal/week	$ 71.090
0,92 gal/day	$ 7.872	1,38 gal/day	$ 11.848

Table 15
Consumption of pneumatic winch in an underground mine.

	Fuel consumption		Cost
Pneumatic winch	53,76	gal/month	$ 461.691
	13,44	gal/week	$ 115.423
	1,92	gal/day	$ 16.489

the industrial sector is $432. Taking into account an average production of 12 tons per day, we calculated the costs of the fuel used to extract the cars from the underground mine (table 14). In the case of internal combustion engines, there is a waste of fuel in the multiple turns on and off that must be made for the ascent and descent of the cars.

The use of the pneumatic winch is challenging in the mine due to the limited use of air compressors. At the time the pneumatic winch is used the other tools used connected to the air compressor must be disconnected, and yet the winch needs more air consumption than the compressor can provide (table 15). In order to avoid this inconvenience, a compressor of greater capacity is needed, which due to their high cost are not used in small mines.

The electric winch is ideal for use in these small mines (Fig. 16). The cost of preventive maintenance is low as it is limited to general cleanliness and maintaining lubricating oil levels in the mechanical elements of the reducer. Power consumption is generated only during winch operating times (table 16). The difficulties that arise in the use of this device are only due to the availability of the electrical network.

Table 16
Electric winch consumption in an underground mine.

	Energy consumption		Cost
Electric winch	246,40	kWh/month	$ 106.445
	61,60	kWh/week	$ 26.611
	8,80	kWh/day	$ 3.802

The electric winch is the one with the lowest cost of operation and maintenance. The useful life of this device is superior to that of internal combustion engines since these engines have been dismantled from the original automobiles

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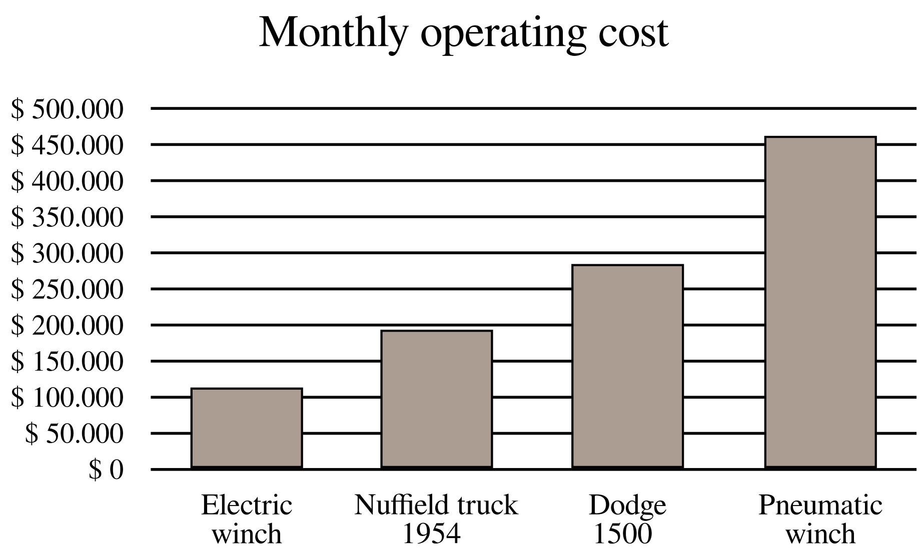

Figure 16. Monthly operating costs for different types of winches in small-scale mining operations.

and have already completed their useful operating cycle. The operating cost of the pneumatic winches is much higher than that of the electric winches and the total disposition of the air compressor is necessary for their satisfactory operation.

Conclusions

In this paper, we detail the design, construction, and operation of an electric winch in a coal mine in the municipality of Samacá, Boyacá (Colombia). For its development, aspects related to the mine were considered, such as its size, type of operation and functional needs. The system also had safety, operational, financial and maintenance criteria.

When implementing the reducer motor control, in addition to performing it under standard and optimizing costs, it was sought to be a simple control, with simple parts to replace since those who operate and maintain the equipment are the same employees of the mine.

Observing the operation of the winch and compared to the internal combustion engine, it is observed that one of the advantages that the first has over the second is that it is maintenance-free but not inspection-free, and another is that energy supplies should not be made that endanger the personnel who perform it (manual fuel supply).

In the calculation of the motor, although it must be approximated to those actually offered by the market, the operation achieved for the winch was optimal. This is guaranteed according to the design and the full load tests carried out, in which the extraction time was very close to the one calculated.

The electric winch is the one with the lowest cost of operation and maintenance. The useful life of this device is higher than that of the internal combustion engines since they have completed their useful cycle of operation.

The operating cost of the pneumatic winches is much higher than that of the electric winches and the total disposition of the air compressor is required for their satisfactory operation.

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