Diploma Thesis

Faculty of Mechanical Engineering

Department of Automotive, Combustion Engine and Railway Engineering

(*Keolis Lyon*: Emmanuel Rodriguez / *CVUT Supervisor*: Jan Kalivoda)

Modernization of a traction system for metro vehicles

MPL75 Traction Chain Improvement

Keolis Lyon

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Diploma Thesis Details

Student: Kenzo SIMOND

Thesis details:

Thesis title	Modernization of a traction system for metro vehicles		
Keywords	Traction chain, MPL75, Asynchronous Motor, Direct Current Motor		
Company	Keolis Lyon		
Tutor from University	Ing. Jan Kalivoda, Ph.D.		
Company tutor	Emmanuel Rodriguez		
Date of assignment	21 March 2017	**Date of handling over**	21 August 2017
Date of defense	15 September 2017		
Written in language	English		

University of the first year: **CTU** **[✓ ENSTA-B]** **TUCH** **ITB**

University of the second year: **[✓ CTU]** **ENSTA-B** **TUCH** **HAN**

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DIPLOMA THESIS ASSIGNMENT

Student: **Bc. Kenzo SIMOND**

Study program: **N2307 Master of Automotive Engineering**

Field of study: **2301T050 Advanced Powertrains**

School year: 2016/2017

Title: **Modernisation of a traction system for metro vehicles**

Assignment:

Compare railway vehicle traction systems based on direct current (DC) and asynchronous (AC) electro-motors.

Propose the replacement of DC traction equipment by AC traction system for Lyon metro vehicle MPL 75. Consider the necessity of installation into the existing bogie and the car body.

Evaluate the benefits of the proposed solution from technical, operational and economical point of view.

Thesis extent: minimally 55 pages

Graphical extent:

Specialized literature list:

Supervisor: Ing. Jan Kalivoda, Ph.D.

Specialist: Emmanuel Rodriguez, Keolys Lyon

Date of thesis assignment: 21 March 2017

Deadline of submission: 21 August 2017

The student acknowledges that he/she must elaborate the project by himself/herself, without any help except consultations with his/her supervisor. A list of used literature, other sources and names of consultants must be listed in the thesis.

I received the assignment on (date): 21 March 2017

Student's signature

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Prague, 10 March 2017

Abstract:

Thanks to the arrival of the new metro MPL16 and the obsolescence of the MPL75 traction chain, it was necessary to consider a switch between the current MPL75 traction chain and the new generation of the MPL16 traction chain (asynchronous motor).

A comparison between DC Motor and Asynchronous Motor revealed that the second one is more robust, requires low maintenance and is lighter and smaller than the DC Motor for the same output power.

To determine if the MPL16 traction chain can work on the MPL75, some simulations of traction performances in different modes, travel time and consumed energy were done. Following the results, with an addition of a boost to cross the maximum slope of the line A, the MPL75/NewGeneration (with the MPL16 traction chain) corresponds to our need. In addition, the difference of the travel time is negligible and the MPL75/NG consumes much less energy than the current MPL75 traction chain.

Finally, it was necessary to verify the feasibility of the installation in the MPL75 and to evaluate the benefits of this modification. Financially and mechanically, this modification is possible and benefic. In fact, if we change the MPL75 traction chain, we can have a gain on the consumed energy and on the labor cost. In addition, it allows to have only one equipment for two different metros (more comfortable for the maintenance workshop).

Acknowledgements:

Before any development in this diploma thesis, I want to thank Keolis and especially Keolis Lyon for it welcome and proposing me a subject which met my expectations.

I want to thank my internship adviser Jean François Blanc, manager of the unit “Développement Métro et Sécurité des Transports Guidés”, for giving me his time to explain the operation and work of a Manager in a company such as Keolis. I also thank Emmanuel Rodriguez, Project Manager and Expert “Matériel Roulant” (Rolling Stock), who helped me a lot during this internship and who was understanding, supportive and pedagogue.

Thanks to all people that I had worked with during this internship, who have been able to show me a true spirit of solidarity and mutual aid.

Contents

Introduction:

This diploma thesis aims to provide a feasibility study of changing and modernizing the traction chain of the MPL75 to improve its overall reliability, to decrease the number of maintenance operations and to handle component obsolescence (by integrating new generation power components) so that it can continue to operate until 2030 or 2035 on the line A in addition to the new metro MPL16 (which will operate on the line B). As the MPL75 direct current electric power train (traction chain) is obsolete, it is necessary to consider a redesign of it with a modification of electric motor into an alternating current motor with an adaptation of the traction chain (electrical and mechanical interfaces). This solution must be technically, operationally and economically beneficial. To begin this study, I read some books (Ref. [1]), studies (Ref. [2]) and thesis (Ref. [3]) which help me to structure my thesis.

This diploma thesis describes, inter alia, the different types of electric motors. Firstly, it describes a Direct Current Motor with a definition of its operating principle, its different parts (rotor, stator, brushes, etc…), its main characteristics and then its advantages and disadvantages. In comparison with this section, a first presentation of the traction chain of the MPL75 could be done. Then, in a third part, it describes the different types of Altering Current Motors (Synchronous and Asynchronous) with a description of them, and especially the Asynchronous Motor which is the considered solution to modernize the current traction chain of the MPL75. Finally, we could compare these two types of electro-motors and to theoretically prove that the considered solution is correct.

To make this feasibility study, we had to collect some characteristics of the MPL75 and the MPL75 New Generation which has an asynchronous traction motor (power, voltage, rotational speed, and different masses) as the new metro MPL16. Thanks to these information (the difference of mass and motorization), we could compare the both traction performances and the possible installation into the existing bogie and then to validate the new solution.

Finally, we evaluated the economic benefits of this considered solution with a study of the current and the future maintenance and a study of the impacts of this solution.

1. Context and Objective of the project

The rolling stock “Métro Pneu Lyon” (MPL75) has two motor cars and a trailer. However, its design provided for the addition of an extra trailer. A train of four cars has been circulating for several years on the B line. Today, trains only run with three cars.

Currently, it seems possible to extend the life of the MPL75 beyond 2030 or 2035. As the MPL75 direct current electric power train (traction chain) is obsolete, it is necessary to consider a redesign of it with a modification of electric motor into an alternating current motor with an adaptation of the traction chain (electrical and mechanical interfaces) thanks to the arrival of the new metro MPL16 which has a new generation traction chain.

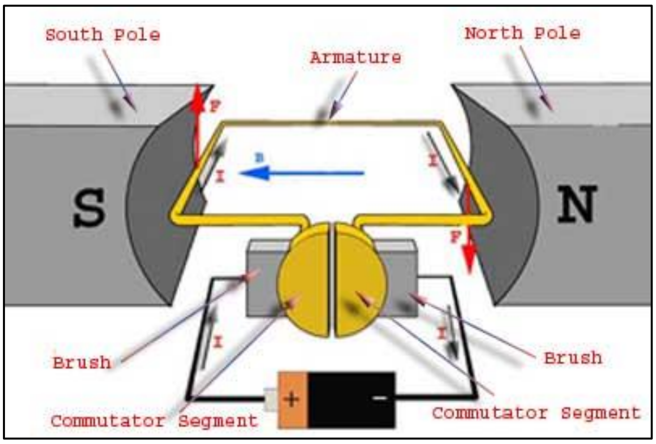
Nowadays, the MPL75 is over-motorized with four motor bogies due to its original design with four cars. The MPL75 is composed of two motor bogies per motor car (four in all) and two carrier bogies. A motor bogie contains two driving axles fitted with a differential and a central DC motor connected by elastic couplings. Then, a train contains four electric DC motors.

2. DC Motor

Based on Ref. [4], [5], [6] and [7]

2.1. Principle of DC Motor

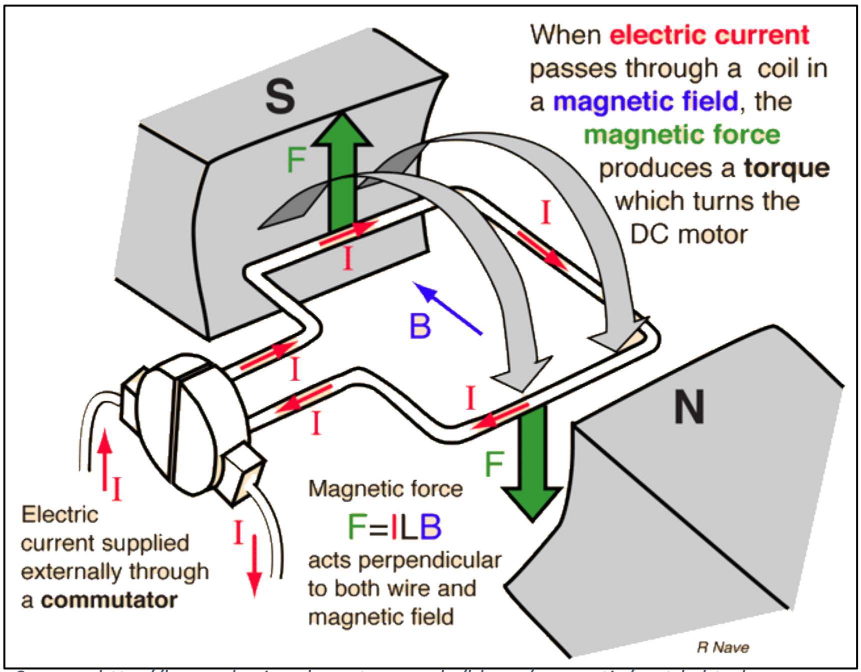
The principle of the DC motor is to convert direct current (DC) electrical energy into mechanical energy. It consists of a stator (inductor) an armature (rotor) with windings of insulated wire which are energized by a commutator though brushes.



Source: Ref. [4]

Figure 1: Schema of the principle of DC Motor

A stator magnetic field B is created by permanent magnet or excitation coil supplied from the DC source. The rotor winding (armature conductors), which can rotate, is placed in this stator magnetic field B. This armature is energized by a direct current which creates a rotating magnetic field. This rotating field across the armature reacts with the stator magnetic field to create a force F on the rotor winding which causes it to rotate. This force F acts on both conductors and we have $\vec{F} = I.\,\vec{l} \wedge \vec{B}$. With the Fleming's left hand rule, we can determine the direction of the force which acts on the both conductors. So, there are two forces created. Each of these acts on a conductor in the opposite direction and creates a torque.



Source : http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/motdc.html

Figure 2: Schema of the operation of DC Motor

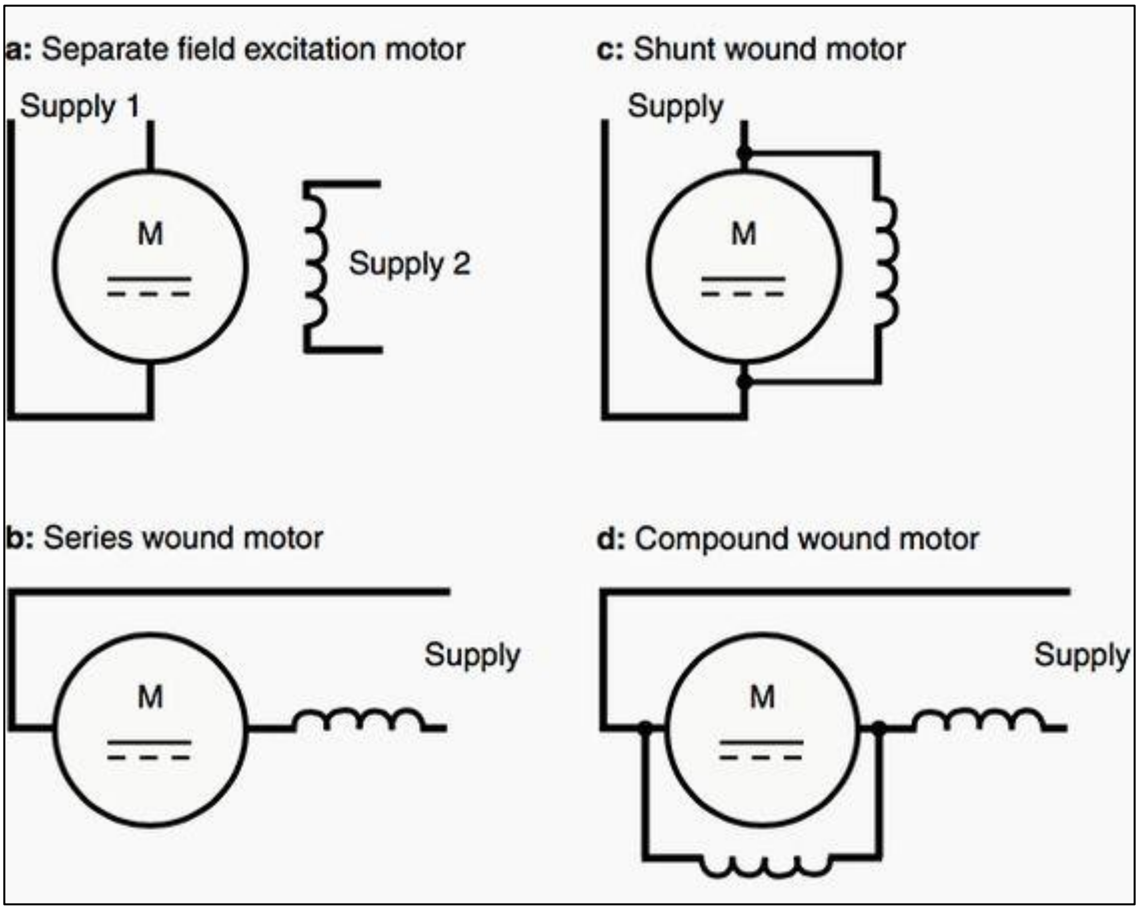
The brushes allow the rotor winding to continue its rotation when it reaches the perpendicular position. In fact, the brushes allow the current direction in the both conductors to commutate when this position is reached. The direction of the current is inverted, the direction of the force is too (Fleming's left hand rule) and the rotation can continue.

The DC Motor is a reversible machine, it can operate in:

- Motor when the load is resistive, it converts electric energy into mechanical energy;
- Generator when the load is catchy, it products electric energy thanks to the mechanical rotation.

There are 4 types of excitation systems due to the connection of armature winding and the field excitation (stator) winding in the DC Motor:

- Separately excitation, the field excitation winding is independent of the armature winding;
- Serial excitation, the field winding and the armature are connected in series. It is often used for electric traction thanks to its high torque at low speed (start, climb, etc...) and its low torque at high speed but it can be damaged by overspeed;
- Shunt excitation, the field winding and the armature are connected in parallel or shunt. It does not have the same starting torque as a series excited motor. It is often used for industrial tools;
- Compound excitation, the field winding and the armature are connected in two parts, a shunt and a serial combination to give the both advantages. It has a high torque at low speed and a good speed regulation (no damaged by overspeed).



Based on Ref. [6]

Figure 3: Schemas of the different excitations

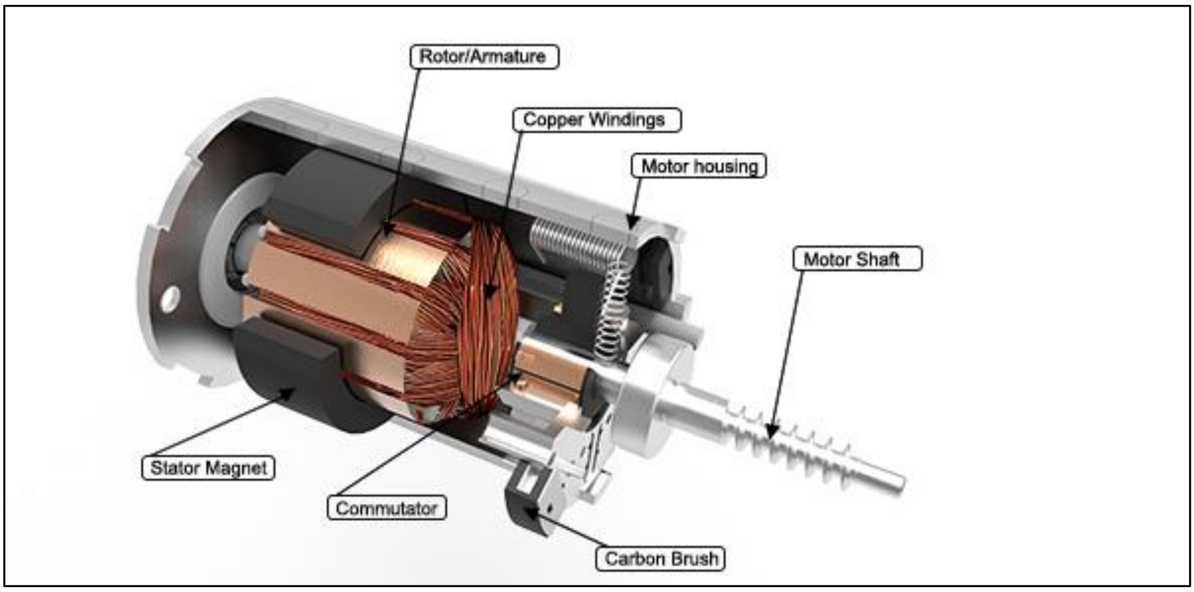
2.2. Components of the DC Motor

2.2.1. Inductor / Stator

In the DC Motor, the stator is the stationary part. It consists of permanent magnets or winding of excitation coil to create the magnetic field thanks to the electric current which passes through this winding. When the stator is composed of permanent magnets, there are not power losses by Joule heating but the magnetic excitation field is constant. This solution is more expensive depending on the size of the motor.

2.2.2. Armature / Rotor

The rotor of the DC Motor is composed of iron laminated sheets package. Into the package slots, rotor winding is immersed. This is very difficult to product and it is expensive. Winding ends are connected to the commutator which is created by the copper lamellas. By means of carbonic brushes, rotor winding is connecting to the fix part of machine. This technology allows to create a rotating magnetic field which interacts with the magnetic field created by the stator and generates the rotation.



Source : https://www.timotion.com/it/news-content/1481266229/278

Figure 4: Schema of different components of the DC Motor

2.2.3. Brushes and Commutator

The brushes ensure the transfer of the electric power from the battery to the winding (rotor) inside the motor by friction. It is a conductor. It is made in carbon because of its good conductivity and its low friction coefficient. However, the brushes represent the wear part of the DC Motor, so we need to maintain them regularly. The number of brushes corresponds to the number of main stator poles.

In addition, connected to the commutator, this system allows to switch the current direction in the conductors (rotor) and then to continue the rotation of the rotor. The most common degradation of the commutator is the short circuit due to the wear of the brushes.

2.3. Speed Control

As we can see in the ideal electric circuit of a rotor, when the rotor is supplied by a source of direct voltage U, a counter-electromotive force E occurs:

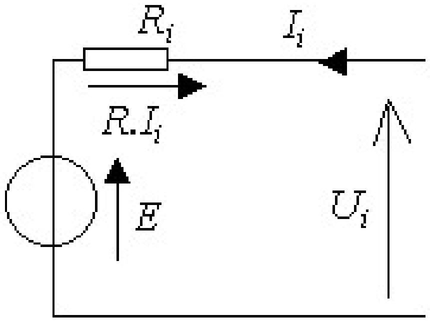
E = U * R.I (in Volt)

R: the resistance in Ohm (Ω)
I: the current of the armature in Ampere (A)

This force E is related to the rotational speed of the rotor:

E = k * w * B (in Volt)

k = constant which depends on the number of conductors
w: the rotational speed in rad/s
B: the magnetic flux in weber



Based on Ref. [6]

Figure 5: Ideal electric circuit of a rotor

Then E is proportional to the rotational speed w and proportional to the voltage U. In conclusion, the rotational speed w is proportional to the voltage U.

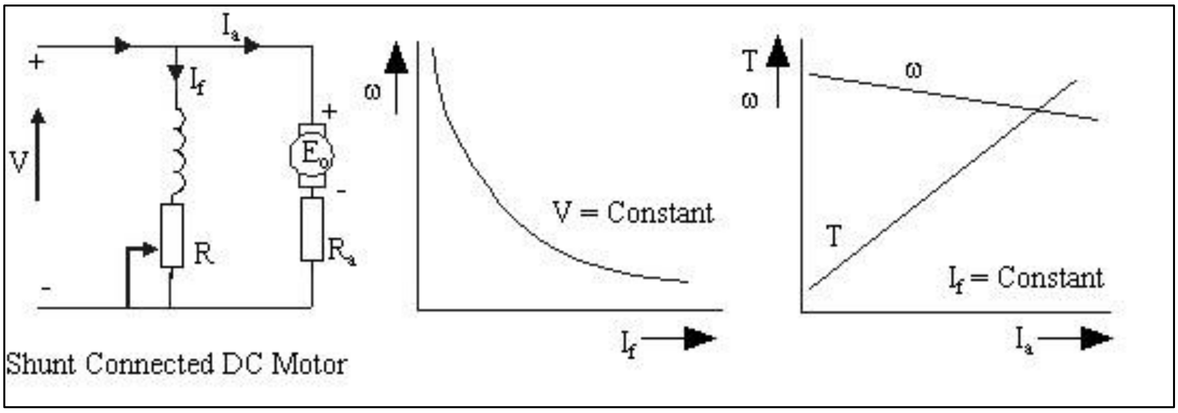
Similarly, the torque motor is proportional to the rotor current:

T = k * B * I (in N.m)

k = constant which depends on the number of conductors
I: the rotor current in ampere (A)
B: the magnetic flux in weber

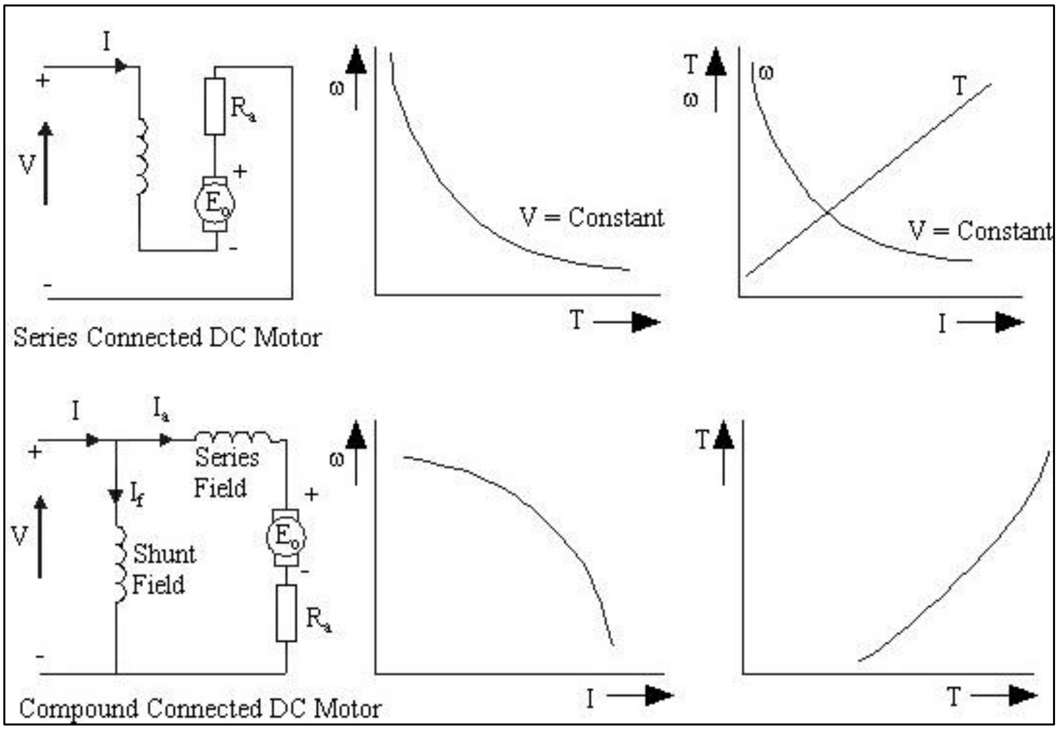
Rotational speed can be control by different parameters:

- To increase the counter-electromotive force E by increasing the armature voltage while maintaining the magnetic flux of the inductor constant (operation at constant torque);
- To decrease the magnetic flux of the inductor by decreasing the current of the armature while maintaining the armature voltage constant (decrease of the torque).



Source : http://myelectrical.com/notes/entryid/153/dc-motor-operation

Figure 6: Characteristics of shunt excited DC Motor



Source : http://myelectrical.com/notes/entryid/153/dc-motor-operation

Figure 7: Characteristics of series and compound excited DC Motors

2.4. Advantages and Disadvantages

Advantages:

- Easy to use and control;
- Perfectly reversible (motor or generator);
- Torque control by induced current control;
- Speed control by voltage control.

Disadvantages:

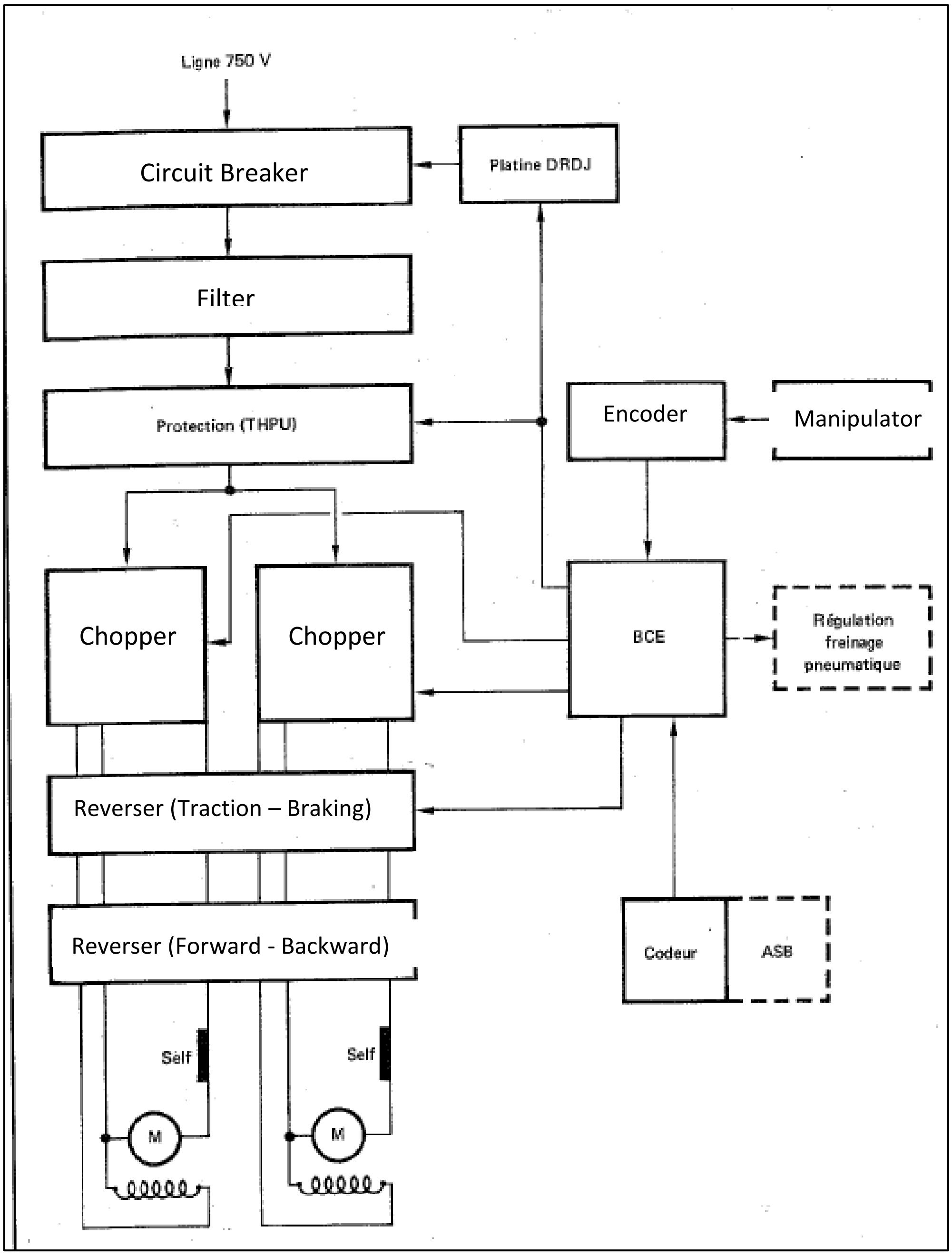
- Slightly robust compared to the AC Motor;
- Expensive and complex manufacturing;
- Recurrent maintenance;
- Limited in speed (due to the commutator).

2.5. MPL75 Traction Motor

Based on Ref. [1] and [8]

The MPL75 traction motor is a series excited DC motor from Alstom (type TAO 673 A1). It is composed of switching pole and compensation winding, it is 4-pole and it is auto ventilated with filter.

To control its rotational speed, the traction chain is composed of choppers (DC voltage converter). There two choppers per motor: a main chopper and a shunting chopper. The main chopper allows to act on the supply voltage and the shunting chopper allows to modify the current of the inductor. There is other equipment related to the traction chain: a manipulator, a circuit breaker, an input filter, an overvoltage protection system, reverser, etc... (Figure 8)



Based on Ref. [8]

Figure 8: Schema of traction equipment

3. Description of the MPL75 Traction Chain

Based on Ref. [8]

3.1. Electric Traction Motor

The TAO 673 A1 is a series DC Motor, 4-pole, with switching pole and compensation winding. This electric traction motor is composed of:

- The structure (the shell), in two parts with a commutator chamber and a magnetic circuit. There is an air filter chamber on each side of the structure;
- The poles, the main polar masses (1mm thick) and the commutation polar masses (0.5mm thick) consist of magnet sheets. Theses poles are fixed to the structure by two screws;
- The stator windings, the conductor is made of high conductivity electrolytic copper;
- The commutator, the switching lamellas are made of copper with silver;
- Rotor winding, it is corrugated. As stator windings, it consists of high conductivity electrolytic copper sections;
- The brush holders, there are 4 brushes in aluminum bronze. Their maximum wear Is 25mm.

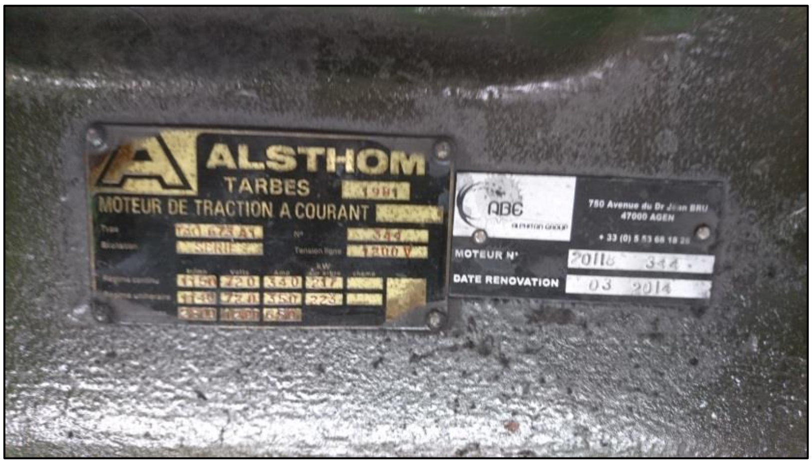


Figure 9: Picture of the electric motor

Motor characteristics are (Table 1 based on Ref. [8]):

	Steady state (max)	Steady state (min)
Voltage	750 V	750 V
Current	340 A	370 A
Speed	1150 rpm/min	2360 rpm/min
Power	217 kW	235 kW

- Maximum operating speed	2800 rpm/min;
- Speed of runaway:	3500 rpm/min;
- Maximum current:	650 A;
- Maximum voltage:	1200 V;
- Isolation voltage:	1800 V;
- Weight without accessories:	1250 kg;

The differential allows the electric DC motor to drive the two axles of the bogie (i.e. the four wheels) and to compensate the difference between the speeds of these two axles due to the tires.

Figure 10: Picture below the MPL75

3.2. Manipulator

The manipulator allows to transmit from the driver's cab:

- In manual driving:
  - Traction, braking and neutral orders;
  - Traction or braking levels;
  - An information for the automatic standby;

- In automatic control:
  - An emergency braking order;

- In both cases:
  - An emergency braking order at the end of the course.

It is fixed in the driver's cab and it is a potentiometer with a rectilinear displacement. In order, we have full traction - zero traction – neutral – zero braking – full braking – emergency braking.

3.3. Encoder

The encoder allows to transmit the voltage levels of traction and braking. We use this devise to have a form less sensitive to interferences than a direct voltage. Therefore, the encoder transforms this direct voltage level into an alternating signal.

This encoder is composed of:

- A supply;
- An oscillator;
- A sawtooth generator;
- Two comparators;
- Two isolating transformers.

3.4. Input Filter

The purpose of this input filter is to limit the influences of the feed line on the choppers and vice versa. This filter is placed at the input of the power circuit of each motor car.

Filter characteristics:

- LC Filter;
- Weight: 230 kg.

3.5. Reversers

These components allow to ensure the commutation in the power command:

- The first one switches between the traction and the braking;
- The second switches between the forward motion and the backward motion.

3.6. Choppers

There are two choppers in the MPL75 electric traction chain: a main chopper and a shunting chopper. The Choppers allow to vary the revolutionary speed of the electric motor. One of these acts on the supply voltage of the armature and the other one acts on the current of the inductor.

In addition, thanks to a power contactor, the chopper allows to control the current produced by the electric motor when it used as a generator during braking. This power contactor changes the electrical diagram of the choppers and their action, one traction position and one braking position. There is another power contactor (reverser) which permutes the connections of the armature coils to invert the direction of the train (forward and backward motion).

The main chopper supplies the electric motor with a variable voltage: from 50V to the full line voltage. It behaves like a DC / DC voltage reducer. During braking, the electric motor works as a generator, allowing energy recovery.

Characteristics of the main chopper:

- *Traction:*		
	• Input voltage	Min 450 V; Nominal 750V; Max 900 V;
	• Output voltage	Min 50 V; Max 900 V;
	• Output current	Nominal 340 A; Max 650 A;
	• Output peak current	800 A;
- *Braking:*		
	• Input voltage	Min 50 V; Max 900 V;
	• Output voltage	Min 450 V; Max 900 V;
	• Input current	340 A.

The shunting chopper, placed in parallel on the inductor, controls the excitation current of the stator. It works in traction and braking. In traction, the shunting chopper only starts when the main chopper is at full conduction.

Characteristics of the shunting chopper:

- Shunting current	Min 15 A; Max 250 A;

3.7. Circuit Breaker

The circuit breaker allows to isolate as quickly as possible all the traction or braking equipment of a motor car if necessary. It is an electro pneumatic DC circuit breaker, type 2-pole in series, very fast and unipolar. It is triggered by overcurrent or by the absence of control voltage.

Characteristics of the circuit breaker:

- Nominal Current	1000 A;
- Maximal voltage	1000 V;
- Control voltage	97 – 126 V;
- Trigger adjustment current	600 to 3000 A;
- Intervention time	< 4ms;
- Air pressure	5 to 9 bars
- Weight	95 kg.

The current pulse required for the quick tripping of the circuit breaker comes from the quick release circuit board (discharge of capacitors). This pulse must reach a peak current of 400 A in 2 to 3ms. The necessary energy is stored in a battery of chemical capacitors and the discharge of these capacitors is ensured by a thyristor.

4. AC Motor

Based on Ref. [6], [8], [9] and [10]

There are two Alternating Current power supplies: single-phase and polyphase current. The single-phase current is used for low-power applications and vice-versa, the polyphase current is used for high power applications. For an electric traction chain, polyphase current is generally used (three-phase).

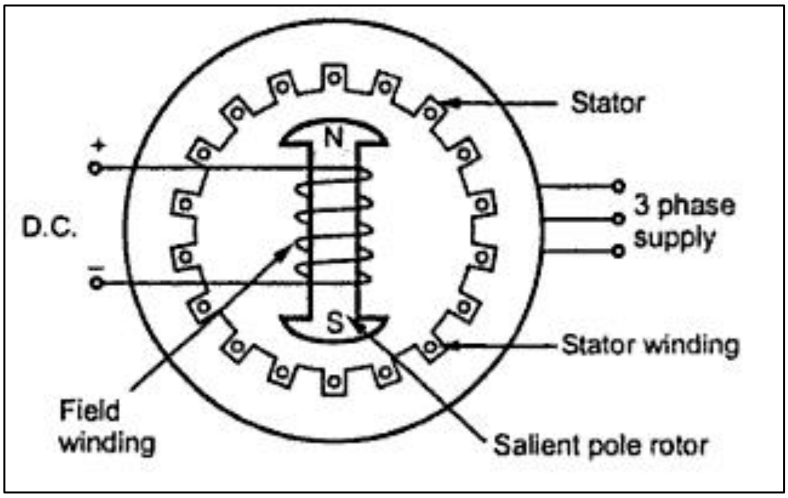
The AC Motor consists of two parts, like the DC Motor, with a stationary stator and a rotor. The stator is composed of coils supplied with alternating current to create a magnetic field which acts with the rotor to produce a rotating magnetic field and create the rotation of the electric motor. The rotor can be composed of permanent magnets, DC windings, Ac windings or reluctance saliency.

There are two main types of AC motors:

- Synchronous Motor;
- Asynchronous Motor.

4.1. Synchronous Motor

The synchronous motor is an electric AC Motor which has a rotation synchronized with the frequency of the supply current. The rotational speed of this motor is proportional to the frequency and the motor toque is proportional to the voltage. It consists of a stationary part (stator) and a rotor which is separated from the stator by an air gap to ensure is mobility. The stator creates a magnetic field which reacts with permanent magnets or electromagnets of the rotor to create the rotation magnetic field. The both magnetic fields create the rotation which is synchronous with them. Without charge, the poles axes of the rotor and the poles axes of the stator are confused. On load, these axes are slightly offset.



Source : Ref. [10]

Figure 11: Schema of an AC Motor

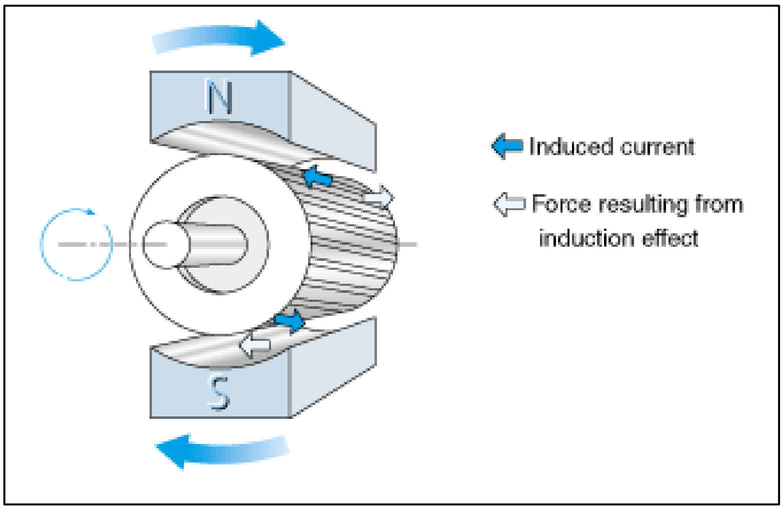
Generally used as a generator, the synchronous machine is called alternator. But it can also be used for electric traction. In this case, the motor must be associated with current inverters. Thanks to this inverter, the motor torque can be control. The synchronous motor operates automatically by monitoring the inductor current with respect to the position of the rotor.

4.2. Asynchronous Motor

The asynchronous motor (also called induction motor) operates thanks to the electromagnetic induction of the rotor from the magnetic field of the stator. In addition, contrary to the synchronous motor, the rotation speed is not synchronized with the frequency of the supply current. This motor is used for high power applications, especially for electric traction in the railway industry. In this case, the asynchronous motor is coupled with a frequency converter to control the rotational speed. In high power applications, this motor is only powered by three-phase current. It can be used as a motor or a generator thanks to the power electronics. This motor is known for its robustness, the low maintenance required and its simple manufacturing.

4.2.1. Principle of Operation

The stator consists of three coils supplied by three-phase current (120°) which create three variable magnetic fields. These three magnetic fields create a rotating magnetic field which drives the rotor thanks to an electromagnetic force. Contrary to the DC Motor, the rotor is not wound all the time. It can be a squirrel cage rotor and consists of two lateral rings connecting several bars. The bars represent the conductors placed in the rotating magnetic field of the stator. Considering the bars are connected by the two rings, the conductors are short-circuited and then create the induction. Then the rotor consists of permanent magnets or DC current windings.



Based on http://www.nidec.com/en-NA/technology/motor/basic/00026/
Figure 12: Schema of the principle of the asynchronous motor

The rotation of the rotor can be varied by controlling the current induced in the conductors and then varying the rotating magnetic field created in the stator. The rotor tries to make up for the rotating magnetic field. Therefore, the flow variation must always be done that there will be a torque in terms of the conductors. If the conductors rotate at the synchronous speed (speed of the rotating field) the flow variation becomes equal to zero and the torque disappears. The rotational speed is thus always below the synchronous speed. This difference is represented by the slip.

The synchronous speed n_s is the rotation rate of the rotating field (stator's magnetic field):

$$\boldsymbol{n_s} = \frac{2*f}{p} \quad \text{(in Hz)} \ ; \qquad \boldsymbol{n_s} = \frac{2*f}{p} * 60 \quad \text{(in RPM)}$$

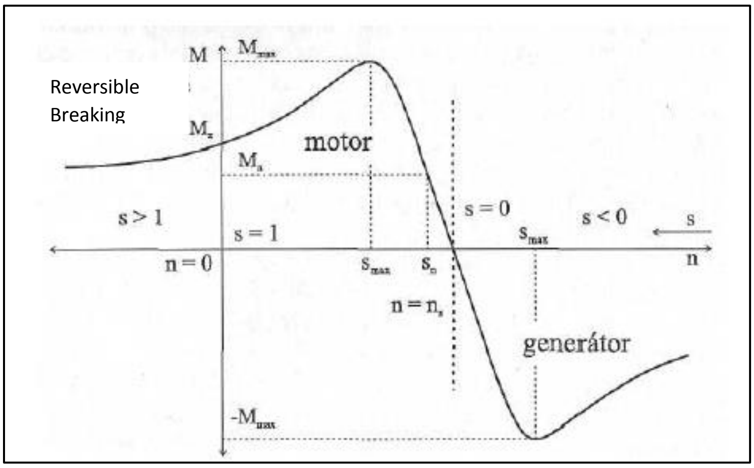
f: the frequency in Hz
p: the number of poles

4.2.2. Slip

The slip represents the difference between the synchronous speed and the rotational speed of the rotor. Therefore, it is defined as the difference between the rotational speed of the motor and the speed of the rotating field (stator's magnetic field):

$$\mathbf{S} = \frac{n_s - n_r}{n_s}$$

n_s : the synchronous speed / the speed of the rotating field of the stator
n_r : the mechanical speed / the rotational speed of the motor



Source: Ref. [9]

Figure 13: Graphic representation of the torque as a function of the rotational speed and the slip

The slip varies between 0 (at synchronous speed) and 1 (the rotational speed is zero). Thanks to it, we can determine the torque of the asynchronous motor. When the slip is small, there is a large current in the rotor and the torque is high.

4.2.3. Torque

The torque of an asynchronous motor is expressed as a function of the power and the rotational speed of the motor:

$$\mathbf{T} = \frac{P*9550}{n} \quad \text{(in N.m)}$$

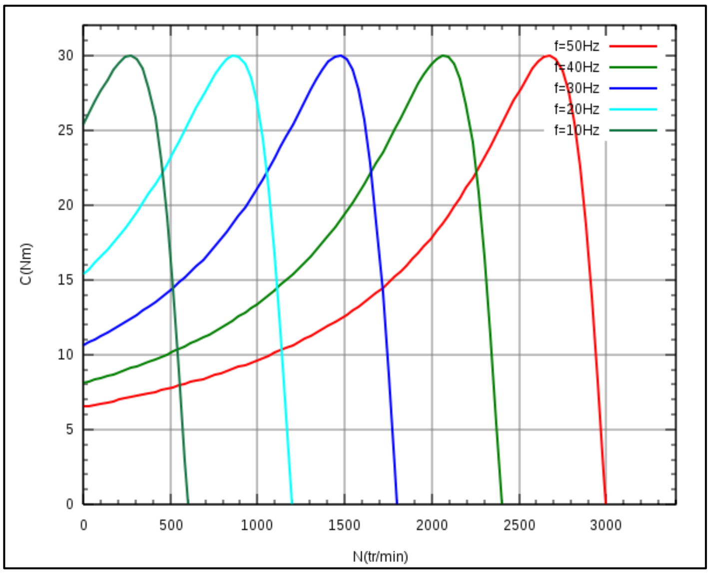
P: the power of the motor
n: the rotational speed

4.2.4. Rotational speed

Rotational speed: $\mathbf{n} = \frac{2*(1-s)*(f*60)}{p}$

(in RPM)

s: the slip
f: the frequency in Hz
p: the number of poles



Source: Ref. [9]

Figure 14: Graphic representation of the torque as a function of the rotational speed and the frequency

The rotational speed of an asynchronous motor is adjustable by varying some parameters such as the number of poles or the frequency.

Therefore, we can obtain various rotational speeds as a function of the number of poles. When we increase the number of poles in an asynchronous motor its rotational speed decreases. But the most common technique to vary the rotational speed is electronically thanks to frequency control with variable speed controllers. When the frequency is changed, the speed of the rotating field changes too and thus the rotational speed of the motor shaft increases (when the frequency increases) or decreases (when the frequency decreases). However, to maintain the torque, the voltage and the frequency must have a constant ration:

$$T = \frac{U}{f} * I \quad \text{(in N.m)}$$

I: the absorbed current by the motor
U: the voltage
f: the frequency

4.2.5. Braking

There are some types of braking in an asynchronous motor:

- Freewheel stop with the stator off;
- Braking with controlled voltage reduction;
- Counter-current stop by switching two phases for a short time;
- Mechanical braking with electric brake and a disc brake controlled by an electromagnet.

5. Comparison DC/AC Motors

	DC Motor	**Asynchronous Motor**
Supply	Direct Current 750V dc + chopper	Alternating Current 750V dc input + inverter
Stator	Inductive windings (high power) Permanent magnets (low power)	Three-phase current in three windings to create a rotating field (120°)
Rotor	Windings of conductors	Squirrel cage rotor (simple motor) Windings (high power)
Rotational Speed	To vary the armature voltage To control the armature current	To vary the frequency To change the number of poles
Efficiency	Medium	Good (losses at the rotor)
Advantages	Simple control of the torque and the speed (separately) Easy to use	Robust and Lighter Low maintenance No commutator
Disadvantages	Recurring maintenance (brushes and commutator) Slightly robust Complex and very expensive production Limited in speed (commutator)	Relationship between speed and load Peak current (start)
Applications	Power generation (generator) Constant speed per load	Industry Alternator (wind turbine, power station)

(Table 2: Comparison DC/AC Motors)

Three-phase asynchronous motor is robust with low maintenance, simple design and not expensive. It is generally used for high power applications and has long service life. In addition, an asynchronous motor has no commutator and thus it is smaller than a DC Motor (for the same output power). This allows us to gain some space in a bogie or to install more power to the same space in a bogie. However, an electric traction chain with an asynchronous motor is characterized by its very high starting torque and its starting peak current. Therefore, it is necessary to add an electronic starting mode which allows to check the motor voltage during the whole start-up phase. It enables to start smoothly without jerking (reduction of the starting current). Finally, this new technology makes the electric braking with energy recovery possible to almost zero speed.

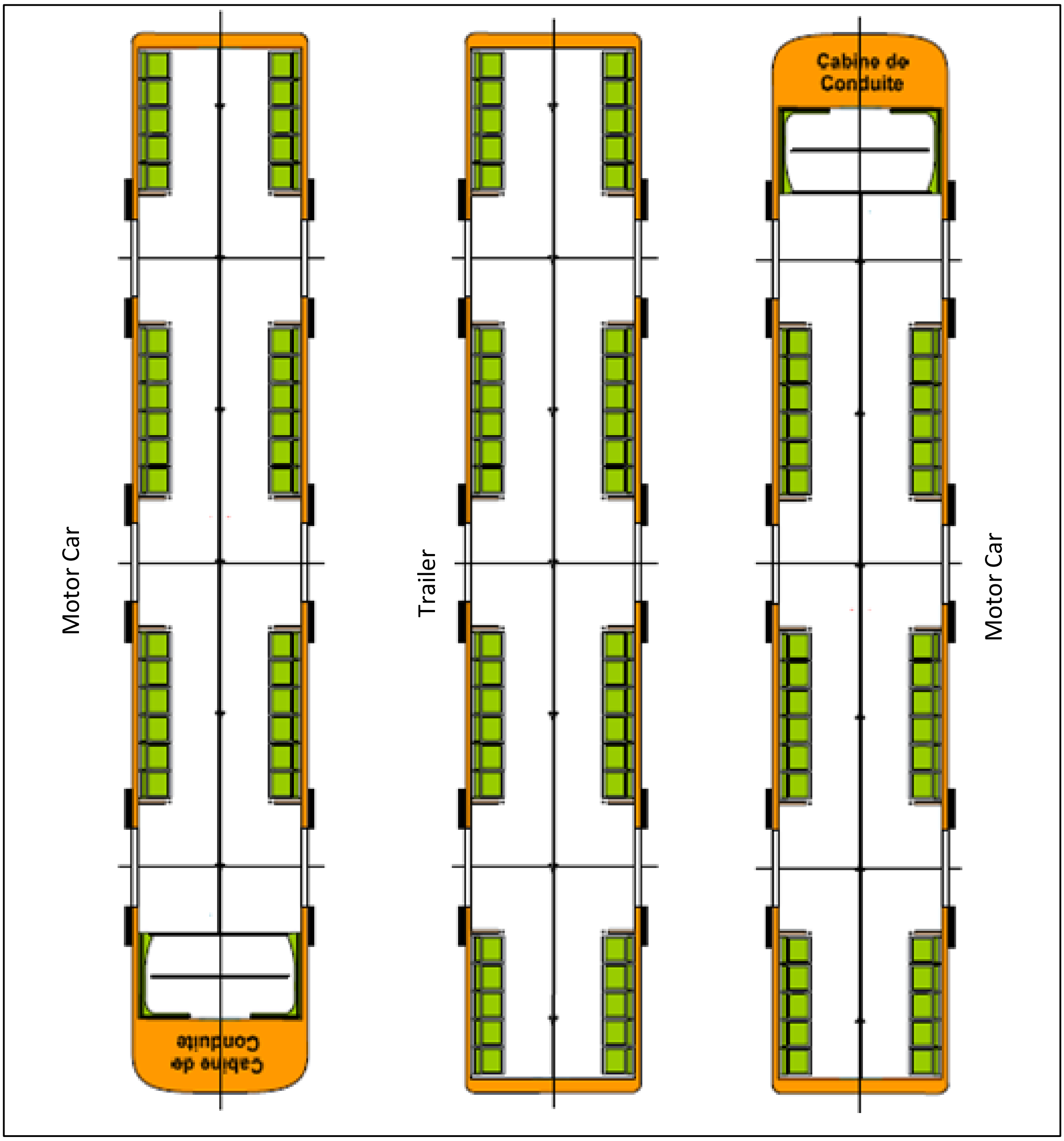
The DC Motor can be used for low power and low voltage as well as for high power applications. It allows a full control of the torque and the rotational speed and it is reversible (motor and generator). However, recurring maintenance is necessary because of the brushes; its cost is very expensive due to its manufacturing cost and maintenance cost and it is limited in speed because of the commutator.

In conclusion, the replacement of DC Motor with asynchronous AC Motor would reduce maintenance operations and thus maintenance costs, increase the performance and decrease the weight.

Equipment removed: reverser and chopper.
New equipment: power and control electronics (inverter).
Equipment replaced: circuit breaker, filter, capacitor and self (smaller and lighter).

6. MPL75 Characteristics

Based on Ref. [8] and [11]



Based on Ref. [11]

Figure 15: Diagram of the MPL75

Main characteristics of the MPL75 (Table 3 based on Ref. [8] and [11]):

Number of Trains	32
Age of MPL75	42
Release	02/05/1978 (20 trains) and 1981 (11 trains)
Number of Cars	3
Composition	Motor – Trailer - Motor

Traction Motor	4 DC Motors 750 V (TAO 673 A1)
Bogies	4 motor bogies and 2 carrier bogies
Train Length	54 376 m
Train Width	2 890 m
Power per Traction Motor	235 kW
Tractive Effort per Motor	40 000 N
Max Speed	90 km/h
Max Acceleration	1.2 m/s²
Max Deceleration	1.96 m/s²
Capacity	428 (max: 744)
Parking Time	25 seconds
Line A Length	18.774 km
Line B Length	15.813 km
Distance Traveled on Line A (2016)	1 656 574 km
Forecast 2030	1 776 379 km
Distance Traveled on Line B (2016)	1 191 516 km
Forecast 2030	1 369 616 km
Number of Passengers on Line A in 2016	64 643 561
Forecast 2030	69 318 657
Number of Passengers on Line B in 2016	44 511 455
Forecast 2030	51 164 770

Some mass characteristics (Table 4 based on Ref. [8] and [11]):

Motor Car	28.7 tons
Trailer	22.6 tons
Empty Train	80 tons
Loaded Train	110 tons (max: 132 tons)
Rotating Mass	10 tons
Rotating Mass of Motor Bogie	2218 kg
Rotating Mass of Carrier Bogie	703.5 kg
Motor Bogie	7465 kg
Motor Bogie without the Traction Motor	6215 kg
Carrier Bogie	4780 kg
[redacted]	[redacted]
Electric Traction Motor	1250 kg
Chopper	300 kg
Reversers	62 kg
Circuit Breaker	95 kg

There are several cases to be considered (Table 5):

	Tare (Empty)	CCN (4 passengers/m²)	CCM (6 passengers/m²)	CCE (8 passengers/m²)
Capacity	0	428	586	744
Mass in the motor car	28.7	38.6	42.3	46
Mass in the trailer	22.6	32.8	36.4	10
Mass (tons)	80	110	121	132

7. MPL75 New Generation Characteristics

7.1. Description of the New Generation Traction Chain

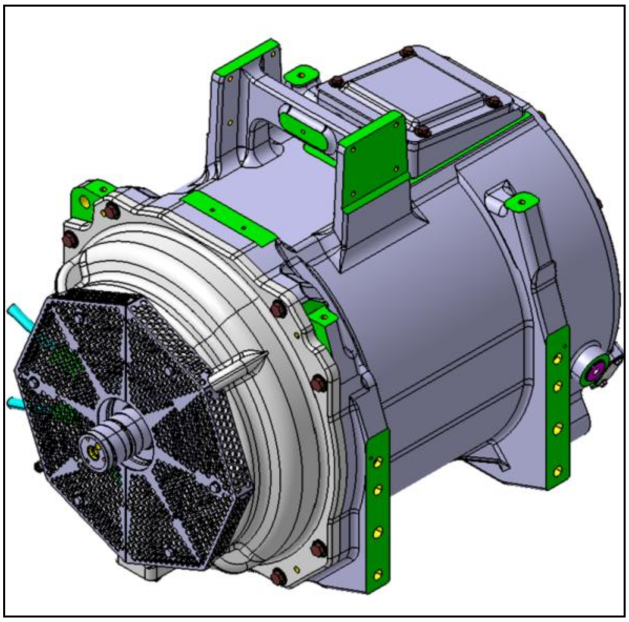
Based on Ref. [12]

The New Generation electric traction chain (which is the same as the MPL16 traction chain) consists of:

- 1 traction box
- 1 self-box
- 1 asynchronous traction motor

The traction box is composed of the main electric equipment of the traction chain: the semiconductor converter, capacitors, the cooling system, control electronics, etc… And the self-box is composed of the input filter inductance and the suppressor resistor (clipping). This box is equipped with a LHD cable (Linear Heat Detector) to detect a fire.

The New Generation Motor is an auto-ventilating 6-poles asynchronous motor. It transforms an electrical energy into mechanical energy during traction and transforms a mechanical energy into electrical energy during braking.



Source: Ref. [12]

Figure 16: Schema of the MPL16 electric motor

Main characteristics of the MPL16 traction chain (Table 6 based on Ref. [12]):

Traction Motor	6- poles asynchronous motor
Number of Motors	2 per train
Power per Traction Motor	290 kW
Rotational speed	1700 rpm
Max Acceleration	1.35 m/s²
Tractive Effort	60 000 N
Voltage	324 V
Frequency	86 Hz
Current	402 A
Power Factor	0.779
Rotating Mass of Motor Bogie	1820.5 kg
Electric Traction Motor	900 kg
Circuit Breaker	37 kg (gain of 58 kg)
Gain with Different Electric Equipment	1000 kg

7.2. Masses Calculations Performed

Mass of motor bogie: 7465 – 1250 + 900 = 7 115 kg

Mass of the motor car without bogie: 28700 – 2*7465 – 300 – 62 – 58 – 1000 = 12350 kg

Mass of the motor car: 12350 + 7115 + 4780 = 24 245 kg (for 1 motor bogie)

Mass of train: 2*24245 + 22600 = 71.09 tons (for 2 motor bogies)

Rotating mass: 1820.5*2 + 703.5*4 = 6455 kg (for 2 motor bogies)

Possible gain of mass:

- Mass of train: 80 – 71.09 = 8 910 kg (for 2 motor bogies) -> - 11.14 %
- Rotating mass: 10 – 6.455 = 3 545 kg (for 2 motor bogies) -> - 35.45 %

Possible new masses of the MPL75/NG (Table 7):

	Tare (Empty)	**CCN (4 passengers/m²)**	**CCM (6 passengers/m²)**	**CCE (8 passengers/m²)**
Capacity	0	428	586	744
Mass of Train	71.09 tons	101.05 tons	112.11 tons	123.17 tons

Then, there is a huge possible gain of mass if we change the traction chain of the MPL75.

8. Traction Performances MPL75 and MPL75/NewGeneration

Based on Red. [13] (Appendix 1)

These results come from simulation software provided by Keolis. This software allows to calculate the permissible slope and the acceleration as a function of different parameters that I modified against the MPL75 parameters. I especially modified the mass, the tractive effort and the motorization rate to calculate the traction performances:

Force (N) = Mass (kg) * Acceleration (m/s²)

Acceleration (motor) = $\frac{\boldsymbol{Tractive\ Effort - (Tensile\ Strength * Mass\ of\ Train)}}{\boldsymbol{Mass}}$

Acceleration (adhesion) = $\frac{\boldsymbol{Adhesion\ Force - (Tensile\ Strength * Mass\ of\ Train)}}{\boldsymbol{Mass}}$

With Mass = Mass of train + Rotating mass

And the Adhesion Force is calculated with the adhesion coefficient, the motorization rate, the mass of train and g-force.

With the maximum acceleration, we can calculate the permissible slope:

Acceleration = g-force * sin (α);   with α: slope angle

8.1. Nominal Mode

Calculations made thanks to the software Ref. [13]

Here are the maximum accelerations and the permissible slopes of the MPL75. The calculation of the permissible slopes is carried out for a minimum acceleration of 0.1m/s².

Traction performances of the MPL75 (Table 8: Keolis source data):

	Tare	CCN	CCM	CCE
Traction motor				
Max acceleration (m/s²)	1.67	1.23	1.11	1.02
Max permissible slope (%)	18.37	12.63	11.26	10.13
Adhesion				
Max acceleration (m/s²)	2.09	2.16	2.17	2.19
Max permissible slope (%)	22.78	22.81	22.82	22.83
Conclusion				
Max acceleration (m/s²)	1.67	1.23	1.11	1.02
Max permissible slope (%)	18.37	12.63	11.26	10.13

Traction performances of the MPL75/NG (Table 9: new data calculated with the software Ref. [13]):

	Tare	CCN	CCM	CCE
Traction motor				
Max acceleration (m/s²)	1.44	1.01	0.90	0.82
Max permissible slope (%)	15.08	9.89	8.68	7.70
Adhesion				
Max acceleration (m/s²)	0.98	1.00	1.01	1.01
Max permissible slope (%)	9.74	9.75	9.77	9.77
Conclusion				
Max acceleration (m/s²)	0.98	1.00	0.90	0.82
Max permissible slope (%)	9.74	9.75	8.68	7.70

On the line A, the maximum slope is 3.62%. The permissible slopes of the MPL75/NG (with 2 motor bogies) exceed this limit. Therefore, the MPL75/NG can operate on line A.

In addition, the maximum acceleration is less than the maximum operating acceleration (1.2 m/s²).

8.2. Downgraded Mode

Calculations made thanks to software Ref. [13]

The downgraded mode consists of a loss of 50% of the motorization. We divide the tractive effort by 2, so 30 000 N per motor bogie (60 000 N in all against 120 000 N in nominal mode) and we also divide the motorization rate.

Traction performances of the MPL75 (Table 10: Keolis source data):

	Tare	CCN	CCM	CCE
Traction motor				
Max acceleration (m/s²)	0.79	0.56	0.50	0.46
Max permissible slope (%)	7.88	5.13	4.47	3.90
Adhesion				
Max acceleration (m/s²)	0.99	1.03	1.03	1.04
Max permissible slope (%)	10.24	10.27	10.27	10.29
Conclusion				
Max acceleration (m/s²)	0.79	0.56	0.50	0.46
Max permissible slope (%)	7.88	5.13	4.47	3.90

Traction performances of the MPL75/NG (Table 11: new data calculated with the software Ref. [13]):

	Tare	CCN	CCM	CCE
Traction motor				
Max acceleration (m/s²)	0.67	0.45	0.40	0.35
Max permissible slope (%)	6.32	3.79	3.20	2.71
Adhesion				
Max acceleration (m/s²)	0.44	0.45	0.45	0.45
Max permissible slope (%)	3.72	3.74	3.75	3.76
Conclusion				
Max acceleration (m/s²)	0.44	0.45	0.40	0.35
Max permissible slope (%)	3.72	3.74	3.20	2.71

On the line A, the maximum slope is 3.62%. The permissible slopes of the MPL75/NG exceed this limit. Therefore, the MPL75/NG cannot operate on line A with 50% of its motorization. We must add a boost because from the CCM (6 passengers per m²), the maximum permissible slope is lower than 3.62% and considerably lower with 8 passengers per m² (CCE).

We can see that the NG has a lack of power to cross the maximum slopes of the line A (3.1%, 3.2% and 3.62%). Consider the use of a booster to add about 20% for the maximum torque to cross these slopes. The tractive effort is 60 000N, so 12 000N is added to each motor.

Traction performances of the MPL75/NG with a booster (Table 12: new data calculated with the software Ref. [13]):

	Tare	CCN	CCM	CCE
Traction motor				
Max acceleration (m/s²)	0.82	0.56	0.50	0.45
Max permissible slope (%)	8.06	5.00	4.29	3.71
Adhesion				
Max acceleration (m/s²)	0.44	0.45	0.45	0.45
Max permissible slope (%)	3.72	3.74	3.75	3.76
Conclusion				
Max acceleration (m/s²)	0.44	0.45	0.45	0.45
Max permissible slope (%)	3.72	3.74	3.75	3.71

This booster allows to increase the performances of the MPL75/NG and to cross the maximum slope of the line A (3.62%).

8.3. Assist Mode

Calculations made thanks to software Ref. [13]

When a train is out of order, another train comes to assist it by pulling or pushing. On line A, this assist mode is done only with empty trains.

For these simulations, we add the mass of the train assisted and the mass of the train which assists and we make the same thing for the rotating masses. In addition, we take the adherence rate and the tractive effort of the train which assists.

8.3.1. Assist Mode with two MPL75

These are the results of maximum acceleration and maximum permissible slope (for motorization and adherence) for a MPL75 which assists another MPL75. *(Keolis source data)*

Table 13: Traction Performances for Assist Mode with two MPL75

	Tare
Traction motor	
Max acceleration (m/s²)	0.79
Max permissible slope (%)	7.88
Adhesion	
Max acceleration (m/s²)	0.99
Max permissible slope (%)	10.24
Conclusion	
Max acceleration (m/s²)	0.79
Max permissible slope (%)	7.88

8.3.2. Assist Mode with two MPL75/NG

These are the results of maximum acceleration and maximum permissible slope for a MPL75/NG which assists another MPL75/NG. *(new data calculated with the software Ref. [13])*

	Tare
Traction motor	
Max acceleration (m/s²)	0.67
Max permissible slope (%)	6.32
Adhesion	
Max acceleration (m/s²)	0.44
Max permissible slope (%)	3.72
Conclusion	
Max acceleration (m/s²)	0.44
Max permissible slope (%)	3.72

Table 14: Traction Performances for Assist Mode with two MPL75/NG

On the line A, the maximum slope is 3.62%. The permissible slopes of the MPL75/NG exceed this limit. Therefore, the MPL75/NG can assist another MPL75/NG.

8.3.3. Assist Mode with a MPL75/NG which assists a MPL75

The Assist Mode with a MPL75 which assists a MPL75/NG is obvious. In fact, the MPL75 New Generation is lighter than a MPL75. Then, the MPL75 will have no problem to assist a MPL75/NG.

These are the results of maximum acceleration and maximum permissible slope for a MPL75/NG which assists a MPL75. *(new data calculated with the software Ref. [13])*

	Tare
Traction motor	
Max acceleration (m/s²)	0.61
Max permissible slope (%)	5.79
Adhesion	
Max acceleration (m/s²)	0.40
Max permissible slope (%)	3.39
Conclusion	
Max acceleration (m/s²)	0.40
Max permissible slope (%)	3.39

Table 15: Traction Performances for Assist Mode with a MPL75/NG and a MPL75

Like the Downgraded Mode, the maximum slope of the line A cannot be crossed if a MPL75/NG assists a MPL75. We must take some special dispositions to reach the end of the line A which has this maximum slope of 3.62%. However, it is not the same problem. Firstly, in this case, the MPL75/NG cannot assist a MPL75 only at the end of the line A when the slope is at 3.62%. Secondly, this case is not a problem with the traction but with the adhesion. A booster will not change anything.

However, to make this simulation, we took a minimum wheel/line adhesion of 0.35 which does not reflect reality. Indeed, the adhesion is higher in the real cases. In addition, the other parameters are chosen so that we have the most critical situation.

For example, by increasing the adhesion to 0.36, the maximum permissible adhesion slope is close to the maximum slope of the line A: 3.6%.

9. Emergency Braking

The current emergency braking was originally designed for a CCE load, including the rotating masses, i.e. 132+10 = 142 tons.

The total mass of the MPL75/NG is 123.17+6.455 ≈ 130 tons. Therefore, this mass is lower than the design load. There is no need to resize the emergency braking.

10. Travel Time on Line A

Calculations made thanks to software Ref. [14]

We must compare the travel times on line A of the NG with those of the MPL75, considering the same characteristics speed templates, parking time, etc… The following results are calculated on a complete turn. These results come from simulation software also provided by Keolis. This software allows to calculate the travel time and the consumed energy as a function of different parameters that I modified against the MPL75 parameters. I especially modified the mass and the regenerative braking rate (35% of regenerative braking for the MPL75 and 60% for the MPL75/NG). The software knows the parking time, the distance of the line A and thanks to the previous results it also knows the speed, the acceleration, etc…

Load	**Function Type**		**Travel Time**	
		MPL75 (Keolis Data)	**MPL75/NG (calculated data Ref. [14])**	**Difference**
Tare	Race on the Wander	43’57.6’’	43’43.7’’	- 13.9’’
CCN	Race on the Wander	44’20.7’’	44’11.3’’	- 9.4’’
CCM	Race on the Wander	44’36.9’’	44’33.8’’	- 3.1’’
CCE	Race on the Wander	45’0.9’’	44’58.8’’	- 2.1’’
CCN	Stretched Mode (Traction)	44’08.5’	43’42.2’’	- 26.3’’
CCE	Stretched Mode (Traction)	44’52.7’’	44’44.2’’	- 8.5’’
CCN	Downgraded Mode (50% motorization) Race on the Wander	49’25.5’’	49’41.9’’	+ 16.4’’
CCN	Downgraded Mode (50% motorization) Stretched Mode (Traction)	49’23.8’’	49’41.2’’	+ 17.4’’
CCM	Downgraded Mode (50% motorization) Race on the Wander	50’27.8’’	51’07.8’’	+ 40.0’’
CCM	Downgraded Mode (50% motorization) Stretched Mode (Traction)	50’26.5’’	51’07.5’’	+ 41.0’’

Table 16: Travel Time on Line A, Comparison between MPL75 and MPL75/NG (calculated with Ref. [14])

In nominal mode, MPL75/NG with 2 bogie motors is faster than the MPL75 on line A for the normal loads. However, in downgraded mode, the MPL75/NG is slower than the MPL75 but this mode is unusual. Then, this loss of time is not a problem and it is not a huge loss of time.

11. Consumed Energy

Calculations made thanks to software Ref. [14]

We must compare the consumed energy if we keep the MPL75 or if we change it to the MPL75 New Generation with the new traction chain. Thanks to the different previous results, we can have the consumed energy (for the different loads) during a round on the line A which is 18.774km.

For that, we had to take some hypothesis:

- The efficiency of the traction chains is equal (in reality, the efficiency will be better for the NG);
- The energy recovery is 35% for the MPL75 (measured value) and 60% for the MPL75/NG. This value is underestimated in relation to what is expected.

Energy Balance of the MPL75 (in kW.h): (Table 17: Keolis source data)

Loads	Consumed Energy	Energy Recovery	Balance
Tare	167.45	17.29	150.16
½ CNN	200.57	21.29	179.28
CNN	239.85	26.39	213.46
CCM	262.76	29.11	233.65
CCE	281.33	31.06	250.27

Energy Balance of the MPL75/ NG (in kW.h): (Table 18: new data calculated with the software Ref. [14])

Loads	Consumed Energy	Energy Recovery	Balance	Difference with MPL75
Tare	143.79	34.88	108.91	- 41.25
½ CCN	170.27	41.62	128.65	- 50.63
CCN	199.07	48.94	150.13	- 63.33
CCM	224.06	54.95	169.11	- 64.54
CCE	250.27	60.66	189.61	-60.66

On the line A (18.774km the round), we estimate per year the number of kilometers:

- 2016: 1 656 574 km;
- 2030: 1 776 379 km;
- 2035: 1 816 166 km.

We also had to take some hypothesis to calculate the consumed energy per load:

- Tare represents 5% of the distance travelled;
- ½ CCN represents 50% of the distance travelled;
- CCN represents 35% of the distance travelled;
- CCM represents 10% of the distance travelled.

The load CCE is extremely rare, so we should not take it into account.

I estimated the distances travelled on the line A in 2030 and in 2035, compared to 2016. This allows me to calculate the number of round per year on the line A and to estimate the energy balance.

Distance travelled in kilometers of the MPL75 per year and until 2035 on the line A (Table 19: calculated data):

Distance Travelled (km)	2016	2030	2035
Tare	82 829	88 819	90 958
½ CCN	828 287	888 190	909 583
CCN	579 801	621 733	636 708
CCM	165 657	177 638	181 917

Rounds on the line A of the MPL75 per year and until 2035 (Table 20: thanks to the distance of the line A: 18.774km):

Rounds on the line A	2016	2030	2035
Tare	4 412	4 731	4 845
½ CCN	44 119	47 310	48 449
CCN	30 883	33 117	33 914
CCM	8 824	9 462	9 690

Consumed energy of the MPL75 on the line A per year and until 2035 (in kW.h): (Table 21: Keolis source data)

Consumed Energy	2016	2030	2035	Total (2016-2035)
Tare	738 770	792 198	811 280	15 500 499
½ CCN	8 848 915	9 488 877	9 717 434	185 663 490
CCN	7 407 332	7 943 037	8 134 360	155 416 920
CCM	2 318 533	2 486 212	2 546 097	48 646 297
Total	19 313 549	20 710 323	21 209 171	405 227 206

Energy recovery of the MPL75 on the line A per year and until 2035 (in kW.h): (Table 22: Keolis source data)

Energy Recovery	2016	2030	2035	Total (2016-2035)
Tare	76 282	81 798	83 768	1 600 499
½ CCN	939 290	1 007 220	1 031 481	19 707 712
CCN	815 007	873 949	895 000	17 100 073
CCM	256 860	275 436	282 071	5 389 305
Total	2 087 439	2 238 404	2 292 320	43 797 589

Balance from 2016 to 2035: 361 429 617 kW.h if we keep the current MPL75.

Energy Balance of the MPL75/NG per year and until 2035 (in kW.h): (Table 23: new data calculated with the software Ref. [14])

Consumed Energy	2016	2030	2035	Total (2016-2035)
Tare	634 385	680 264	696 649	13 310 342
½ CCN	7 512 114	8 055 397	8 249 427	157 615 408
CCN	6 147 915	6 592 538	6 751 333	128 992 480
CCM	1 977 053	2 120 036	2 171 101	41 481 539
Total	16 271 467	17 448 235	17 868 510	341 399 769

Energy recovery of the MPL75/NG per year and until 2035 (in kW.h): (Table 24: new data calculated with the software Ref [14])

Energy Recovery	2016	2030	2035	Total (2016-2035)
Tare	153 886	165 016	168 990	3 228 769
½ CCN	1 836 226	1 969 023	2 016 451	38 526 771
CCN	1 511 423	1 620 731	1 659 769	31 711 920
CCM	484 866	519 932	532 456	10 173 215
Total	3 986 401	4 274 702	4 377 666	83 640 675

Balance from 2016 to 2035: 257 759 094 kW.h if we change the traction chain of the MPL75.

The difference of consumed energy from 2016 to 2035 between the MPL75 and the MPL75/NG is ***103 670 523 kW.h*** (-29%).

Thanks to these estimations, we can also estimate the difference of consumed energy between the MPL75 and the MPL75/NG per year and determine the global economic gain (0.10€ per kW.h):

	2017-2035	2017-2030	2020-2035	2020-2030
Gain	9.9 M€	7.2 M€	8.4 M€	5.7 M€

Table 25: Economic gain thanks to the energy per period

In addition, we are in the most critical situation. So, we can have a minimum gain of 8.4 million of euros until 2035 and 5.7 million of euros until 2030.

12. Installation in the Current Bogie

Based on Ref. [2] and [3]

12.1. To Be Checked

First, we must make sure that dimensions of the new electric motor allow an easy integration in the motor bogie (no changes).

Then, we must check:

- The accessibility and compatibility with some accessories that we will keep (sensors, cable, fuses, etc…);
- The current bogie supports the new constraints generated by the new electric motor;
- The reliability of the current differential;
- The current motor mounts are compatible with the new electric motor (positioning and maintaining);
- The rotation speed must be equivalent to the current electric motor (the new motor must have the same performances);
- The current elastic coupling must be adjustable to the new motor (otherwise it must be changed and a new mechanical interface must be designed);
- The new center of gravity and mass distribution;
- The obsolescence of the electrical wiring (if we prove it is in good condition and suitable to the new motor, we can keep it);
- The information delivered by the manipulator and processed by the relays fits with the new operation;
- What are the asbestos components.

In fact, we must ensure that the new solution does not degrade the current rolling stock MPL75 and its performance.

12.2. Impacts and Recommendations

The circuit breaker, the inductances, the reverser, the filters, etc… must be changed and the choppers must be replaced with an inverter.

Train Mass	- Mass balance - Train braking performance - To check the inflation pressure of the tires - To check that there is no larger load on a wheel
Clamping System	- With equal or decreased mass, to check that can keep the existing fasteners - If we increase the mass, we must provide for reinforcements or new fasteners and check the strength
Electric Braking	- Energy saving - Brake shoe saving
Traction Chain	- To ensure that the manipulator is compatible with the new solution - The new solutions must work until 2030 / 2035 - The new solution does not have a reverser - To check the compatibility of the current differential and the bogie - To check the harmonics of the new electric motor that could disturb the system or cause a motor overheating
Time + Maintenance	- To check the deployment time of this new solution (feasibility study, tests, etc…) - This time will have an impact on the availability of the rolling stock MPL75 and on the organization of the maintenance - To plan the staff training for maintenance on these new equipment - Updating the maintenance plan
Cost	- Low maintenance costs (less operations and greater periodicity) - Complete change of the traction chain -> high cost

Table 26: Impacts and recommendations (based on Ref. [2])

13.Maintenance

Based on Ref. [15]

13.1. Regular Maintenance

Preventive Maintenance (control):

- Forward and Backward Motion
- Emergency Braking
- Alarm
- Standby function
- Three-way valves
- Door closure
- Deceleration
- Isolation of the motor car
- Ventilation
- Pneumatic.

Figure 17: Picture of one of the choppers

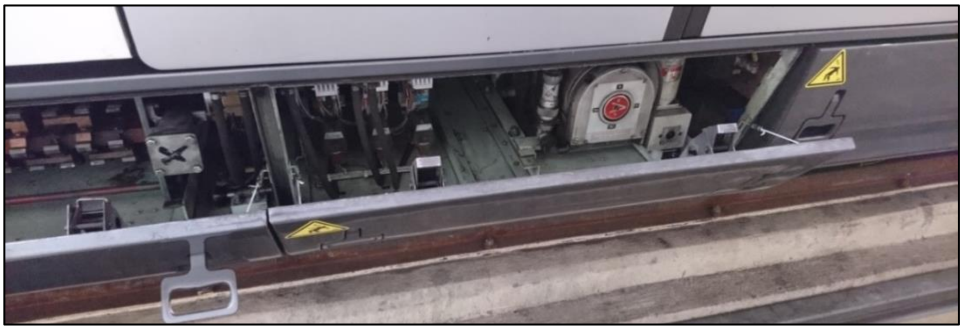


Figure 18: Picture of a box with some contactors and fuses

Maintained parts:

- Boxes:
  - Electro-pneumatic Contactor
  - Reverser
  - Circuit Breaker
  - Isolator
  - Contactors
  - Relays
  - Self (inductance)
  - Capacitor
  - Filter
  - Resistance
  - Chopper
  - Fuse
  - Diode

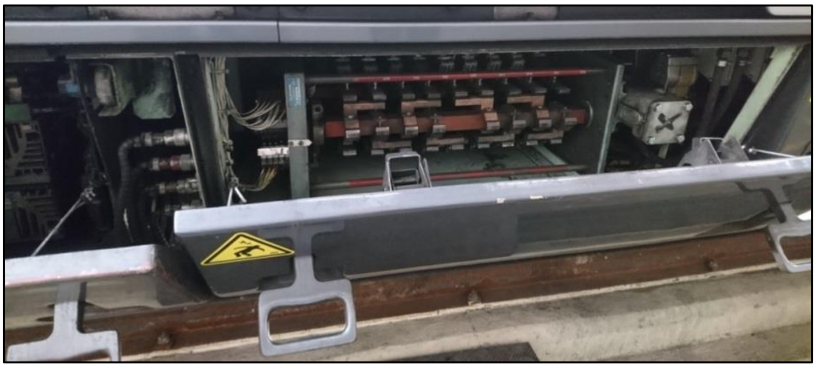


Figure 19: Picture of the reverser

Figure 20: Picture of the box with ventilation and diodes

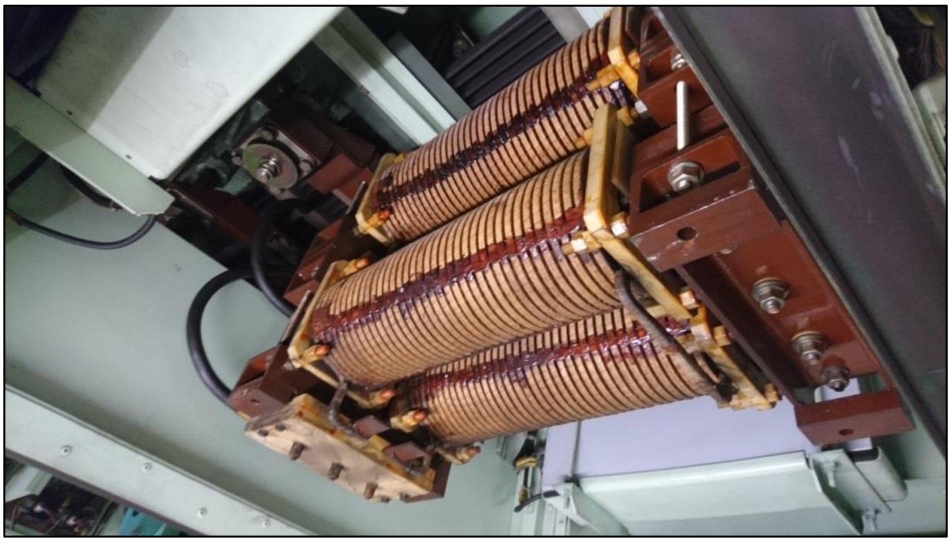


Figure 21: Picture of the main inductance

- Current Collector Shoe:
  - Positive current collector shoe
  - Negative (Earth ground) current collector shoe
  - Shunt
  - Articulated support for the positive current collector shoe

Figure 22: Picture of the positive current collector shoe

- Electric Motor:
    - Motor mount
    - Electric traction motor
    - Elastic coupling
    - Commutator chamber
    - Commutator
    - Brushes
    - Isolator
    - Filter
    - Sensor
- Tire:
    - Train wheel (iron wheel)
    - Brake lining
    - Wheelhouse (linkage)
    - Suspension
    - Brake cylinder.

Figure 23: Picture of the elastic coupling

Regular maintenance for electric motor (Table 27 based on Ref. [15]):

DC Motor	Distance (km)	New (Asynchronous) Motor	Distance (km)
Cleaning of the Commutating Chamber	16 500		
Filter Replacement	25 000		
Commutator or Brushes Control	33 000	Dusting of the Ventilation Grid	32 000
Rating of the Brushes	33 000		
Cleaning of the Brushes	33 000		
Cleaning of the Commutating Gate	33 000		
Cleaning of the Filters	33 000		
Cleaning of the Vacuum Nozzles	66 000		
Greasing the Bearings	66 000		
Bearings Control	75 000		
		Motor Fasteners Control	120 000
		Greasing the Bearings	120 000

Regular maintenance for traction chain (Table 28 based on Ref. [15]):

Current Traction Chain	Distance (km)	New Traction Chain	Distance (km)
Circuit Breaker	8 250		
Functional Check	8 250		
Filtering Inductance (self)	17 000	Filtering Inductance	17 000
		Circuit Breaker	17 000
Commutator Control	33 000		
Brushes Control	33 000		
Sensors	33 000		
Contactors	33 000		
Filters	33 000		
Reverser	66 000		
Chopper	66 000		
		Filters	152 000
		Inverter or Boxes	200 000

New traction chain: fewer operations, easier operations and greater periodicity. Then the train can work longer than the current MPL75.

13.2. Asset Maintenance

The asset maintenance is done every 700 000km for the DC Motor and every 1 100 000km for the Asynchronous Motor.

DC Motor	New (Asynchronous) Motor
Electrical Separating Measures	Electrical Separating Measures
Cleaning and Steaming	Cleaning and Steaming
Bearings Replacement	Bearings Replacement
Anti-Flash Paint	Anti-Flash Paint
Turning / Grooving of the Commutator	
	Cleaning of the ventilation ducts
Brushes replacement	
Brushes Compression Spring Replacement	
(Motor) Elastic Coupling Balancing	
Adjusting the Air Gap	
(Neutral) N-Line Control	
Test Bed	Test Bed

Table 29: Asset Maintenance, Comparison between DC and AC Motor based on Ref. [15]

New Motor: fewer operations, easier operations and greater periodicity

13.3. Maintenance Time

Current Traction Chain (Replacement + Test)	**Repair Time**	**New Traction Chain (Replacement + Test)**	**Repair Time**
Manipulator	1h00	Manipulator	1h00
Circuit Breaker Control Board	1h00		
Braking Protection Fuses	1h30	Braking Protection Fuses	1h30
Circuit Breaker of the Chopper	1h30		
Brake Shoe	2h00	Brake Shoe	2h00
Negative Current Collector Shoe	2h00	Negative Current Collector Shoe	2h00
Main Circuit Breaker	3h00		
Braking Protective Diode	3h00		
Chopper	3h00	Inverter	3h00
Brake Cylinder	3h00	Brake Cylinder	3h00
Each Electronics Rack (Control, Braking, Chopper, Manipulator)	3h00	Power and Control Electronics	3h00
Sensors	3h00		
Control Card	4h00		
Reverser	4h00		
Electric Traction Motor	4h00	Electric Traction Motor	4h00

Table 30: Time Maintenance (based on Ref. [15])

As there are fewer operations, then there is less maintenance time. In fact, the new traction chain is composed of only two boxes compare to the current MPL75 traction chain which is compose of about one box for each component.

14. Analyze

14.1. Current Maintenance and Estimations

Based on data 2013, 2014, 2015, 2016, 2017 – Ref. [16] (Appendix 2)

In this part, I consider the different interventions on each component of the MPL75 traction chain: brake, collectors, motor, circuit breaker, chopper, etc…

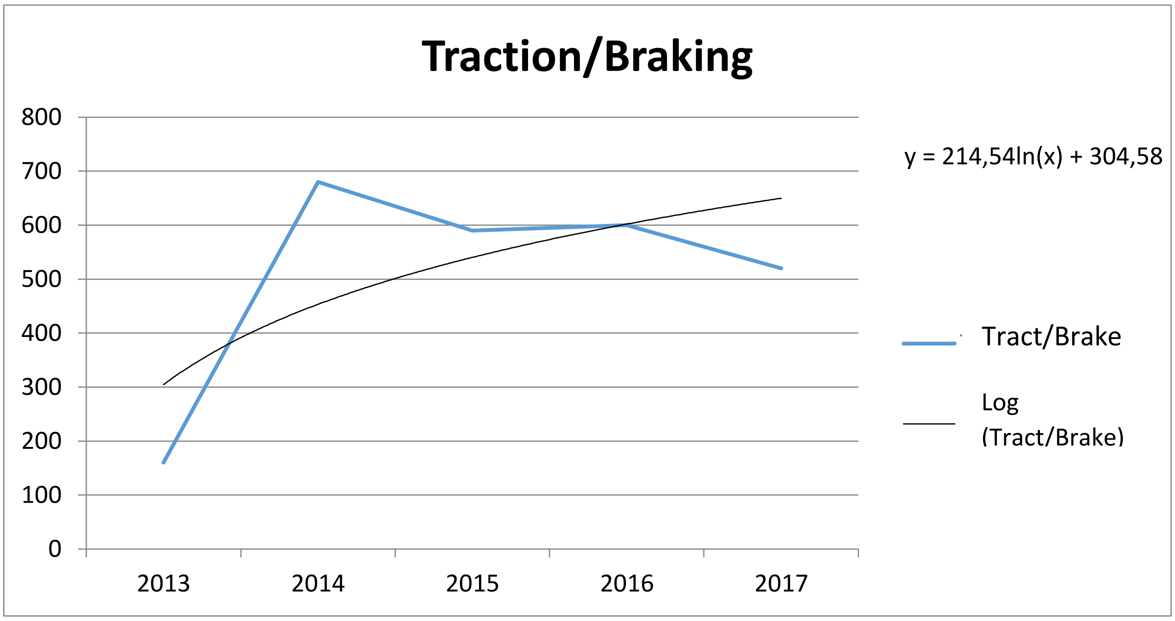


Figure 24: Graphic representation of the number of interventions on the traction chain per year

Hypotheses:

- 3 agents to maintain the different components of the current MPL75 traction chain;
- The labor cost is 51€ per hour;
- 50% of the operations are followed by spare parts (the purchase cost is estimated at about 1M€);
- We must consider the work time (§13.3).

	Number of Operations	Labor Cost (k€)
2016	600	275
Estimation for 2030	930	425
Estimation for 2035	980	450

Table 31: Current Corrective Maintenance and Estimations (operations + cost)

Following the analysis of current corrective maintenance data from 2013 to 2017, I made an estimation (by modeling with a log trend curve) the number of operations over the coming years. Then we will achieve an economic assessment between our two options:

- To keep the current traction chain;
- To change it by the traction chain subsequently shown which represents a lower maintenance.

Finally, I can make a global estimation of the corrective maintenance cost (labor cost + purchase) if we keep the MPL75 traction chain over 13 years (until 2030) and over 18 years (until 2035):

- 6.2 M€ over 13 years (2030);
- 8.4 M€ over 18 years (2035).

14.2. Economic Record

Benefits for maintenance if we change the MPL75 traction chain with the MPL16 traction chain:

- Number of components divided by 2;
- More reliable and modern equipment;
- Number of operations on the electric motor reduced because an asynchronous motor is more robust and requires low maintenance;
- Global number of operations reduced (less components, more reliable, modern, etc…);
- Same equipment as the MPL16 so no different spare parts (better organization) and therefore bigger order so lower price;
- New traction chain therefore potentially 0% of corrective maintenance.

Hypotheses:

- Cost of a new traction chain: 300 k€
- 2 agents to remove and install the traction chain
- The labor cost is 51€ per hour
- There are 8 working hours per day and 250 working days per year
- 70h to remove the current traction chain (4 electric motors and the boxes):
    - *32 trains:* 2240 hours -> 280 days
    - *26 trains:* 1820 hours -> 227 days
- 35h to install the new traction chain (2 electric motors and the boxes) :
    - *32 trains:* 1120 hours -> 140 days
    - *26 trains:* 910 hours -> 114 days
- Gain on the maintenance:
    - *Until 2030:* 6 200 k€
    - *Until 2035:* 8 400 k€
- Gain of energy:
    - *Until 2030:* 5 700 k€
    - *Until 2035:* 8 400 k€

Global Expense (in k€) of the project (Table 32):

	32 trains	26 trains
Purchase Price	19 200	15 600
Labor Cost to remove the current traction chain	228	186
Labor Cost to install the new traction chain	114	93
Total	19 500	15 900

Global work time:

- *32 trains:* 420 days -> 1.7 year
- *26 trains:* 341 days -> 1.4 year

Global Gain (maintenance + energy):

- *Until 2030:* 5.7 + 6.2 = 11.9 M€
- *Until 2035:* 8.4 + 8.4 = 16.8 M€

Balance between Expense and Gain (Table 33):

	32 trains	26 trains
Until 2030	- 7.6 M€	- 4.0 M€
Until 2035	- 2.7 M€	**+ 0.9 M€**

At best, we have a gain of about one million of euros if we change the current traction chain with the new generation (MPL16 traction chain). It is a huge yard (one and a half year) but after that, we will no longer have maintenance on this traction chain and we can concentrate on other preventive and corrective maintenance.

However, there is another solution: we can replace the parts which require a lot of maintenance and are very obsolete like the circuit breaker, manipulator, electronic rack and choppers. The work time and the purchase will be reduced. Therefore, the labor cost and the purchase price will be reduced and the maintenance over 13 or 18 years will be reduced too.

Parts of the traction chain which require the most repair work (Table 34: Keolis source data Ref. [16]):

	2015	2016	2017
Circuit Breaker	13%	11%	11.5%
Manipulator	10%	8%	11%
Electronic Rack	13.5%	17%	14%
Chopper	14%	16.5%	16.5%
Electronic Control Cards	15.5%	13.5%	13%

14.3. Synthesis

We have a work in progress with the arrival of the MPL16 and it is possible to integrate it in the MPL75 bogie (electric motor) and in the boxes of the MPL75. However, it is necessary to cut all the current wiring (electrical and pneumatic) which requires a lot of time and labor.

The cost to modify the current MPL75 traction chain by new generation MPL16 traction chain (asynchronous motor, new generation power components, etc…) is estimated at about 16 million euros (purchase + labor) for the variant which concerns the modernization of 26 trains and which is the recommendation of Keolis Lyon.

The estimation of the corrective maintenance cost for the coming years are approximately 8.5 million euros if we keep the current MPL75 traction chain until 2035. In addition, we have a gain on the consumed energy which amounts to approximately 8.5 million euros with the MPL75/NG. Under the assumption that the modernization of the traction chain will not generate a high maintenance cost (potentially 0% of corrective maintenance), we make a profit of 1 million euros for the variant which concerns 26 trains conserved until 2035.

Multi-criteria analysis (Table 35):

	Current MPL75 Traction Chain	**New Generation Traction Chain**
Modern and Reliable	-	+
Correspond to our Need	+	+
Energy Consumed	-	+
Maintenance Cost	-	+
Organization of the Maintenance Workshop	-	+
Duration of Project	+	-
Solution recommended	-	+

The solution to modernize the MPL75 traction chain is more reliable, corresponds to our need (traction performances and travel time), consumes much less energy and will not generate a high maintenance (potentially 0% of corrective maintenance). However, it represents a huge yard which will be very long. But if we do not modernize it, the corrective maintenance will increase. Then the time to do the modification is nothing compared to the working time spent to maintain this current MPL75 traction chain.

Conclusion

As the MPL75 direct current electric power train (traction chain) is obsolete, it is necessary to consider a redesign of it with a modification of electric motor into an alternating current motor with an adaptation of the traction chain (electrical and mechanical interfaces) like the modern traction chain of the new metro MPL16. So, I had to study the feasibility of changing and modernizing the traction chain of the MPL75 to improve its overall reliability, to decrease the number of maintenance operations and to handle component obsolescence (by integrating new generation power components) so that it can continue to operate until 2030 or 2035 on the line A in addition to the new metro MPL16 (which will operate on the line B).

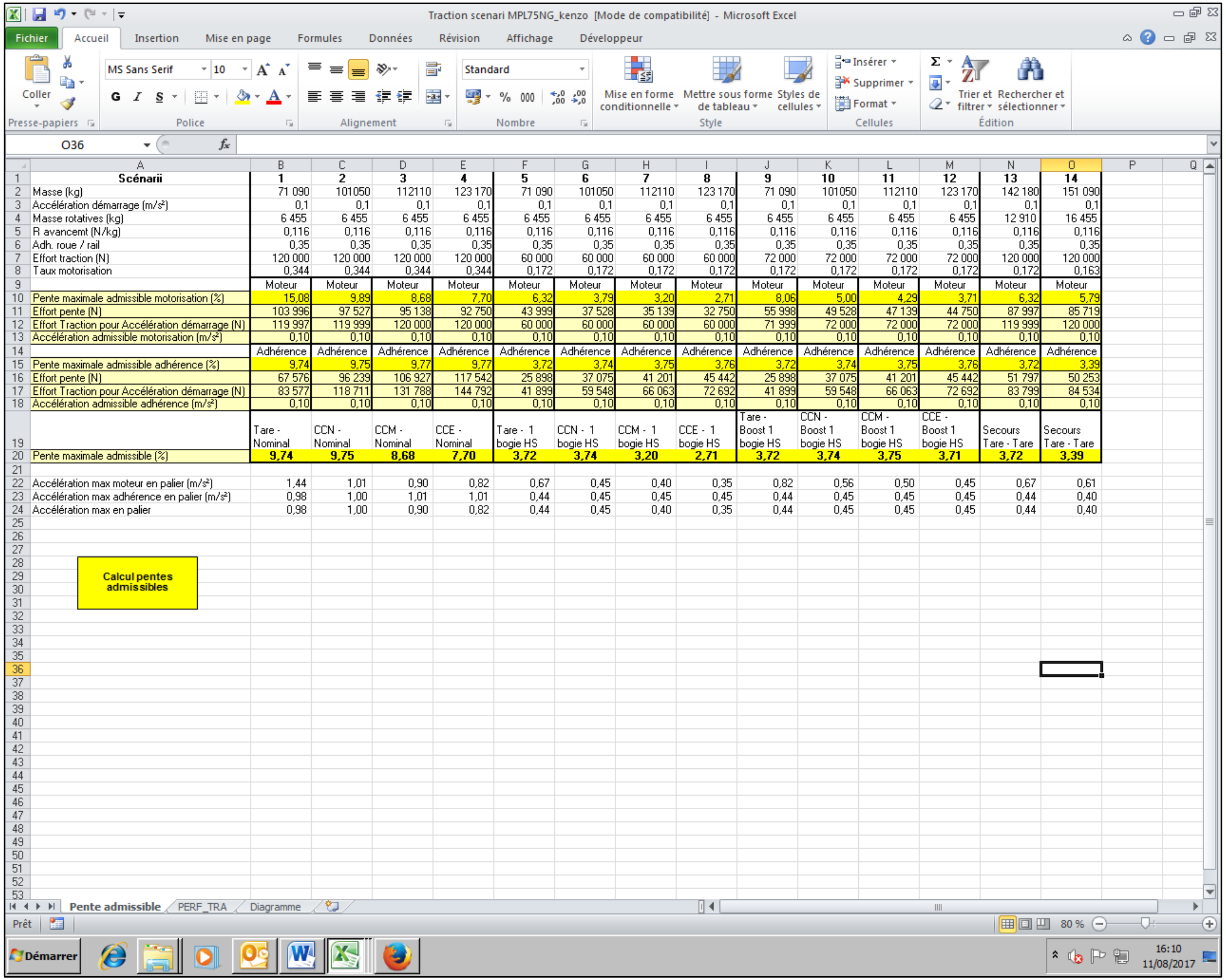
I began with a comparison of the two electric motors, the Direct Current Motor (current MPL75 traction motor) and the Asynchronous Motor (the new generation which will be introduce in the MPL16). According to this comparison, the new generation of electric motor with Alternating Current Motor is more robust, requires low maintenance and is lighter than the previous generation with Direct Current Motor.

Then, I collected some characteristics of the MPL75 traction chain and the MPL16 traction chain which has an asynchronous traction motor (power, voltage, rotational speed, and different masses). Thanks to these information (the difference of mass and motorization), I made some simulations of traction performances, braking performances, travel time and consumed energy. Most of the required performances (acceleration, permissible slope, assist mode, emergency braking and time travel) are reached but we need to add a boost to cross the maximum slope of the line A in the Downgraded Mode. In addition, the consumed energy simulation shows that the MPL75 New Generation (with the MPL16 traction chain) consumes less energy than the current MPL75 and has a better energy recovery during braking. So, there is a huge gain on the energy.

Finally, I studied the current maintenance on the MPL75 and made some estimation over 13 years (until 2030) and 18 years (until 2035). There are a lot of operations on the current MPL75 traction chain and it continues to grow over the years. With a new traction chain, we have no more maintenance, and we also have the same equipment as the MPL16. This last point is important because if we keep the current MPL75 traction chain, we will have two different equipment in the maintenance workshop. This modification is therefore more comfortable. In addition, following the analyze, the economic report is positive with the modification of 26 trains.

Annexes

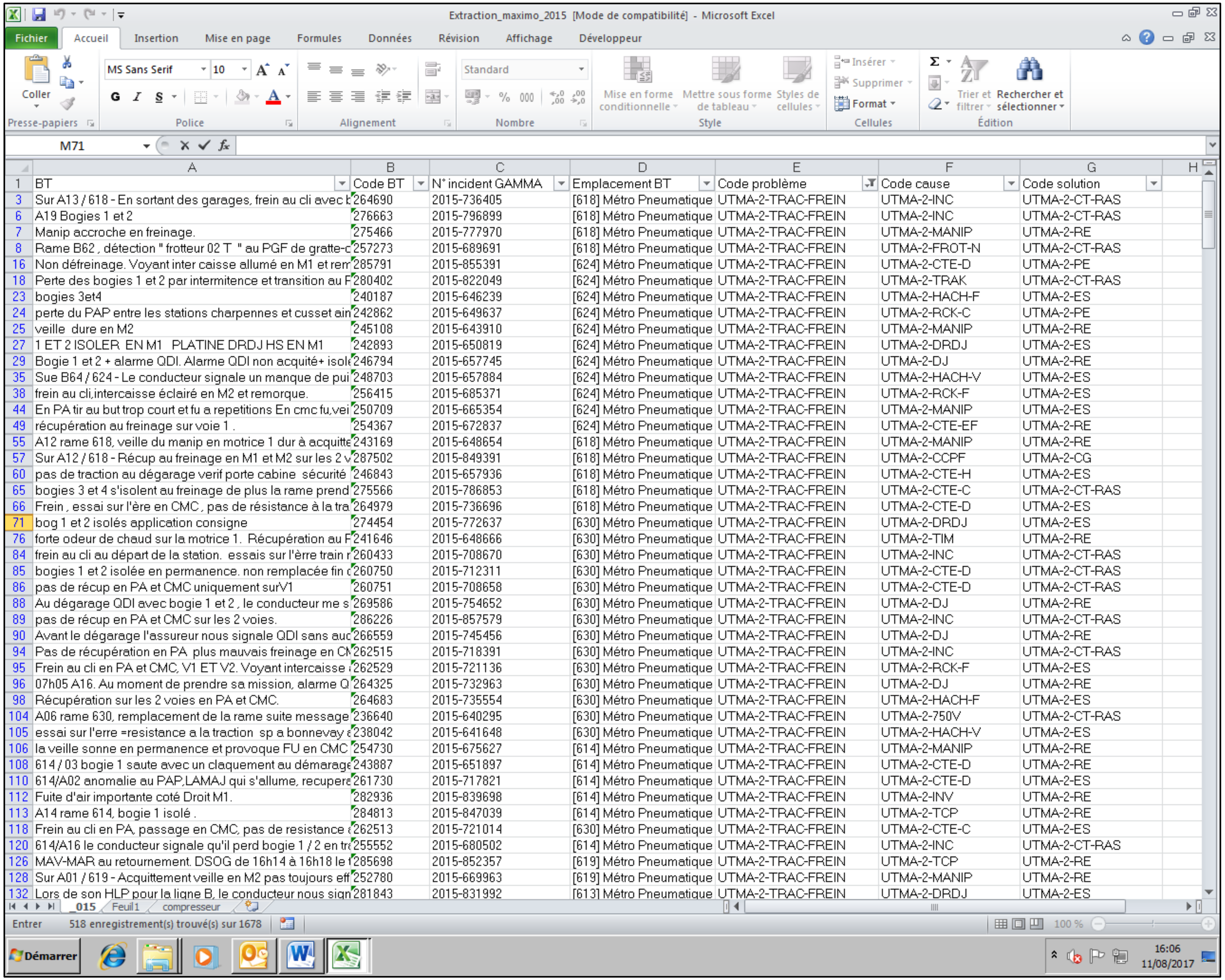
Appendix 1: Ref [13] Traction Performances Software



Scénarii	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Masse (kg)	71 090	101050	112110	123 170	71 090	101050	112110	123 170	71 090	101050	112110	123 170	142 180	151 090
Accélération démarrage (m/s²)	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
Masse rotatives (kg)	6 455	6 455	6 455	6 455	6 455	6 455	6 455	6 455	6 455	6 455	6 455	6 455	12 910	16 455
R avancemt (N/kg)	0,116	0,116	0,116	0,116	0,116	0,116	0,116	0,116	0,116	0,116	0,116	0,116	0,116	0,116
Adh. roue / rail	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35
Effort traction (N)	120 000	120 000	120 000	120 000	60 000	60 000	60 000	60 000	72 000	72 000	72 000	72 000	120 000	120 000
Taux motorisation	0,344	0,344	0,344	0,344	0,172	0,172	0,172	0,172	0,172	0,172	0,172	0,172	0,172	0,163
	Moteur	Moteur	Moteur	Moteur	Moteur	Moteur	Moteur	Moteur	Moteur	Moteur	Moteur	Moteur	Moteur	Moteur
Pente maximale admissible motorisation (%)	15,08	9,89	8,68	7,70	6,32	3,79	3,20	2,71	8,06	5,00	4,29	3,71	6,32	5,79
Effort pente (N)	103 996	97 527	95 138	92 750	43 999	37 528	35 139	32 750	55 998	49 528	47 139	44 750	87 997	85 719
Effort Traction pour Accélération démarrage (N)	119 997	119 999	120 000	120 000	60 000	60 000	60 000	60 000	71 999	72 000	72 000	72 000	119 999	120 000
Accélération admissible motorisation (m/s²)	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
	Adhérence	Adhérence	Adhérence	Adhérence	Adhérence	Adhérence	Adhérence	Adhérence	Adhérence	Adhérence	Adhérence	Adhérence	Adhérence	Adhérence
Pente maximale admissible adhérence (%)	9,74	9,75	9,77	9,77	3,72	3,74	3,75	3,76	3,72	3,74	3,75	3,76	3,72	3,39
Effort pente (N)	67 576	96 239	106 927	117 542	25 898	37 075	41 201	45 442	25 898	37 075	41 201	45 442	51 797	50 253
Effort Traction pour Accélération démarrage (N)	83 577	118 711	131 788	144 792	41 899	59 548	66 063	72 692	41 899	59 548	66 063	72 692	83 799	84 534
Accélération admissible adhérence (m/s²)	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
	Tare - Nominal	CCN - Nominal	CCM - Nominal	CCE - Nominal	Tare - 1 bogie HS	CCN - 1 bogie HS	CCM - 1 bogie HS	CCE - 1 bogie HS	Tare - Boost 1 bogie HS	CCN - Boost 1 bogie HS	CCM - Boost 1 bogie HS	CCE - Boost 1 bogie HS	Secours Tare - Tare	Secours Tare - Tare
Pente maximale admissible (%)	**9,74**	**9,75**	**8,68**	**7,70**	**3,72**	**3,74**	**3,20**	**2,71**	**3,72**	**3,74**	**3,75**	**3,71**	**3,72**	**3,39**
Accélération max moteur en palier (m/s²)	1,44	1,01	0,90	0,82	0,67	0,45	0,40	0,35	0,82	0,56	0,50	0,45	0,67	0,61
Accélération max adhérence en palier (m/s²)	0,98	1,00	1,01	1,01	0,44	0,45	0,45	0,45	0,44	0,45	0,45	0,45	0,44	0,40
Accélération max en palier	0,98	1,00	0,90	0,82	0,44	0,45	0,40	0,35	0,44	0,45	0,45	0,45	0,44	0,40

Figure 25: Screenshot of the traction performances software from Keolis Lyon to calculate the new performances with the new traction chain

Appendix 2: Ref. [16] Maintenance Data



1	BT	Code BT	N° incident GAMMA	Emplacement BT	Code problème	Code cause	Code solution
3	Sur A13 / 618 - En sortant des garages, frein au cli avec	264690	2015-736405	[618] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-INC	UTMA-2-CT-RAS
6	A19 Bogies 1 et 2	276663	2015-796899	[618] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-INC	UTMA-2-CT-RAS
7	Manip accroche en freinage.	275466	2015-777970	[618] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-MANIP	UTMA-2-RE
8	Rame B62 , détection " frotteur 02 T " au PGF de gratte-	257273	2015-689691	[618] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-FROT-N	UTMA-2-CT-RAS
16	Non défreinage. Voyant inter caisse allumé en M1 et re	285791	2015-855391	[624] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-CTE-D	UTMA-2-PE
18	Perte des bogies 1 et 2 par intermitence et transition au	280402	2015-822049	[624] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-TRAK	UTMA-2-CT-RAS
23	bogies 3et4	240187	2015-646239	[624] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-HACH-F	UTMA-2-ES
24	perte du PAP entre les stations charpennes et cusset ain	242862	2015-649637	[624] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-RCK-C	UTMA-2-PE
25	veille dure en M2	245108	2015-643910	[624] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-MANIP	UTMA-2-RE
27	1 ET 2 ISOLER EN M1 PLATINE DRDJ HS EN M1	242893	2015-650819	[624] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-DRDJ	UTMA-2-ES
29	Bogie 1 et 2 + alarme QDI. Alarme QDI non acquité+ isol	246794	2015-657745	[624] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-DJ	UTMA-2-RE
35	Sue B64 / 624 - Le conducteur signale un manque de pui	248703	2015-657884	[624] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-HACH-V	UTMA-2-ES
38	frein au cli,intercaisse éclairé en M2 et remorque.	256415	2015-685371	[624] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-RCK-F	UTMA-2-ES
44	En PA tir au but trop court et fu a repetitions En cmc fu,vei	250709	2015-665354	[624] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-MANIP	UTMA-2-ES
49	récupération au freinage sur voie 1 .	254367	2015-672837	[624] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-CTE-EF	UTMA-2-RE
55	A12 rame 618, veille du manip en motrice 1 dur à acquitte	243169	2015-648654	[618] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-MANIP	UTMA-2-RE
57	Sur A12 / 618 - Récup au freinage en M1 et M2 sur les 2	287502	2015-849391	[618] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-CCPF	UTMA-2-CG
60	pas de traction au dégarage verif porte cabine sécurité	246843	2015-657936	[618] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-CTE-H	UTMA-2-ES
65	bogies 3 et 4 s'isolent au freinage de plus la rame prend	275566	2015-786853	[618] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-CTE-C	UTMA-2-CT-RAS
66	Frein , essai sur l'ère en CMC , pas de résistance à la tra	264979	2015-736696	[618] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-CTE-D	UTMA-2-ES
71	bog 1 et 2 isolés application consigne	274454	2015-772637	[630] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-DRDJ	UTMA-2-ES
76	forte odeur de chaud sur la motrice 1. Récupération au	241646	2015-648666	[630] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-TIM	UTMA-2-RE
84	frein au cli au départ de la station. essais sur l'èrre train	260433	2015-708670	[630] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-INC	UTMA-2-CT-RAS
85	bogies 1 et 2 isolée en permanence. non remplacée fin	260750	2015-712311	[630] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-CTE-D	UTMA-2-CT-RAS
86	pas de récup en PA et CMC uniquement surV1	260751	2015-708658	[630] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-CTE-D	UTMA-2-CT-RAS
88	Au dégarage QDI avec bogie 1 et 2 , le conducteur me s	269586	2015-754652	[630] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-DJ	UTMA-2-RE
89	pas de récup en PA et CMC sur les 2 voies.	286226	2015-857579	[630] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-INC	UTMA-2-CT-RAS
90	Avant le dégarage l'assureur nous signale QDI sans au	266559	2015-745456	[630] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-DJ	UTMA-2-RE
94	Pas de récupération en PA plus mauvais freinage en C	262515	2015-718391	[630] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-INC	UTMA-2-CT-RAS
95	Frein au cli en PA et CMC, V1 ET V2. Voyant intercaisse	262529	2015-721136	[630] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-RCK-F	UTMA-2-ES
96	07h05 A16. Au moment de prendre sa mission, alarme Q	264325	2015-732963	[630] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-DJ	UTMA-2-RE
98	Récupération sur les 2 voies en PA et CMC.	264683	2015-735554	[630] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-HACH-F	UTMA-2-ES
104	A06 rame 630, remplacement de la rame suite message	236640	2015-640295	[630] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-750V	UTMA-2-CT-RAS
105	essai sur l'erre =resistance a la traction sp a bonnevay	238042	2015-641648	[630] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-HACH-V	UTMA-2-ES
106	la veille sonne en permanence et provoque FU en CMC	254730	2015-675627	[614] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-MANIP	UTMA-2-RE
108	614 / 03 bogie 1 saute avec un claquement au démarage	243887	2015-651897	[614] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-CTE-D	UTMA-2-RE
110	614/A02 anomalie au PAP,LAMAJ qui s'allume, recuper	261730	2015-717821	[614] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-CTE-D	UTMA-2-ES
112	Fuite d'air importante coté Droit M1.	282936	2015-839698	[614] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-INV	UTMA-2-RE
113	A14 rame 614, bogie 1 isolé .	284813	2015-847039	[614] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-TCP	UTMA-2-RE
118	Frein au cli en PA, passage en CMC, pas de resistance	262513	2015-721014	[630] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-CTE-C	UTMA-2-ES
120	614/A16 le conducteur signale qu'il perd bogie 1 / 2 en tr	255552	2015-680502	[614] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-INC	UTMA-2-CT-RAS
126	MAV-MAR au retournement. DSOG de 16h14 à 16h18 le	285698	2015-852357	[619] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-TCP	UTMA-2-RE
128	Sur A01 / 619 - Acquittement veille en M2 pas toujours eff	252780	2015-669963	[619] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-MANIP	UTMA-2-RE
132	Lors de son HLP pour la ligne B, le conducteur nous sign	281843	2015-831992	[613] Métro Pneumatique	UTMA-2-TRAC-FREIN	UTMA-2-DRDJ	UTMA-2-ES

Figure 26: Screenshot of the Ref. [16] Extraction_maximo_2015 to extract the maintenance data

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Tables

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