DEVELOPMENT AND USE OF CURRENT CHOPPERS IN ELECTRIC TRACTION

M.T.E. AND JEUMONT-SCHNEIDER COMPANIES

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M.T.E. AND JEUMONT-SCHNEIDER COMPANIES (1)

Research conducted by Jeumont-Schneider in the field of thyristor control of d. c. current traction equipment for locomotives and railcars has resulted in the development of increasingly powerful chopper prototypes which have in every instance been immediately submitted to tests under field conditions followed up by series production.

A well-defined technique is now available making the chopper a convenient and profitable tool for the operator and a quiet partner for the weak-current systems.

The main factor in the rapid development of electronics and electrical engineering was undoubtedly the advent of semi-conductors. In the field of electric railroad traction, this development started in France in the early sixties.

First to be used were silicon diodes which progressively replaced the mercury-vapor rectifiers on the 25 kV-50 Hz single-phase locomotives. The thyristors subsequently permitted simultaneous current rectification and control.

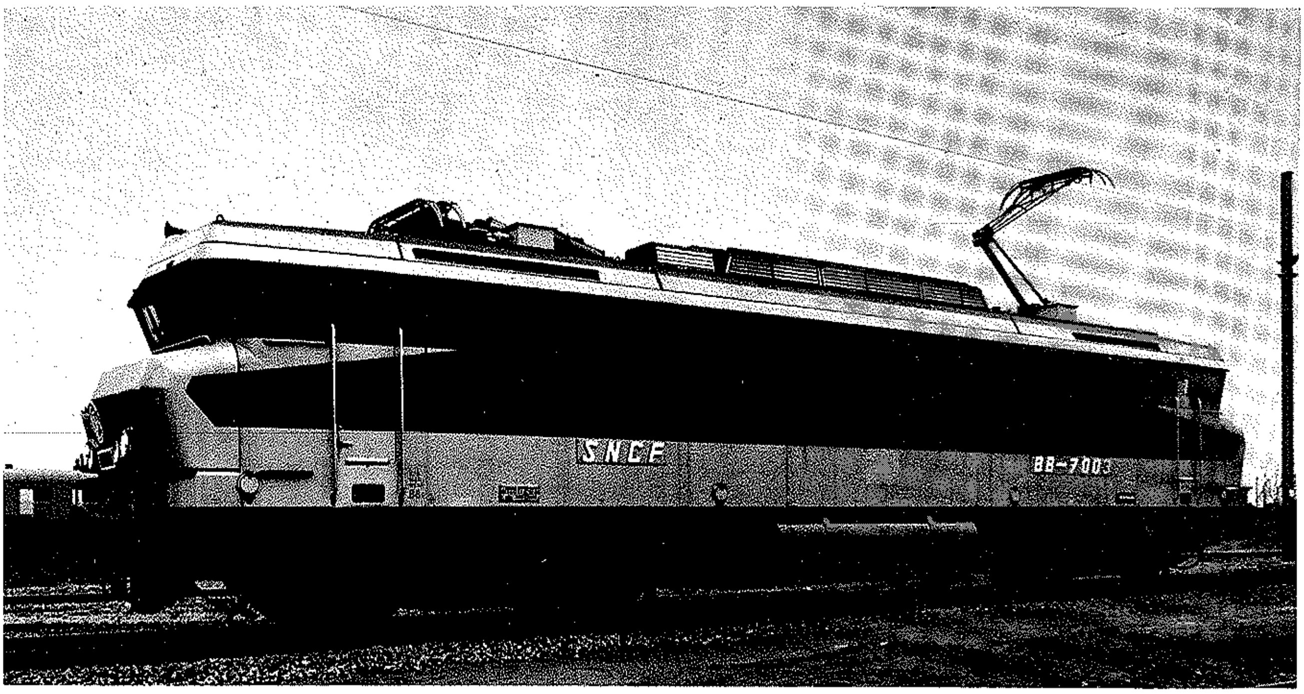
Since 1968, this concept has been used for all single-phase locomotives and railcars.

At about the same time, high-power thyristors of the "fast" type became available enabling the development of the chopper to be used for the control of over head-line-fed d. c. traction motors.

Since 1964, Jeumont-Schneider has carried out a number of experiments with choppers. Between 1968 and 1972, these experiments led to the design of complete traction and braking equipment whose industrial technology could easily be adapted to series production. Performance, service and technology were of such convincing quality that most of the d. c. equipment currently manufactured by Jeumont-Schneider is of the chopper type.

The purpose of this paper is to describe the chopper and its properties. Its performance is compared with that of conventional equipment, but it will be shown that the chopper also has some properties of its own which have no parallel.

Fig. 1. — BB 7003, 1,500 V d. c. S.N.C.F. chopper equipped-electric locomotive.



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(1) This article was written by Pierre Moury, Research Engineer.

THE CHOPPER

Among the semi-conductor converters, the chopper is one of the most simple systems in use. Although its principle is well known, it is still worthwhile recalling some of its features as well as presenting the most commonly used circuits.

OPERATIONAL PRINCIPLES

VOLTAGE REDUCING CHOPPER

The operational principle is shown in Figure 2 where the chopper is represented by a change-over switch.

The main relations between the conduction ratio h and E, i_m, u_m, i_h are easily calculated.

During the conducting interval

$$E = u_m + L\frac{\Delta i_m}{hT}.$$

Fig. 2. — Permanent field weakening resistance.

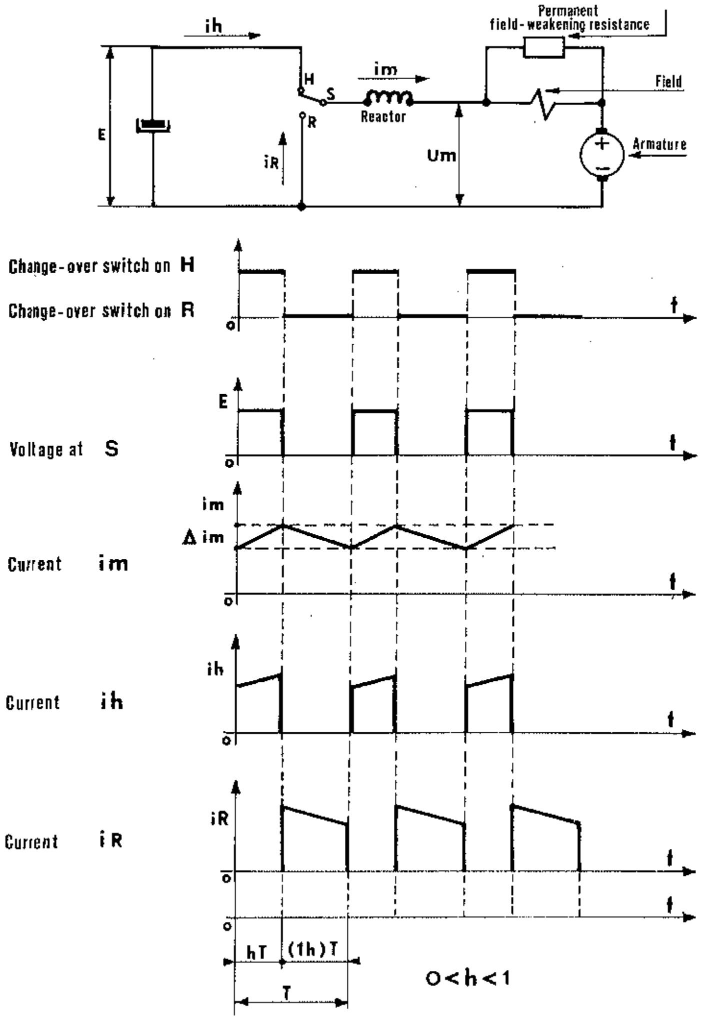
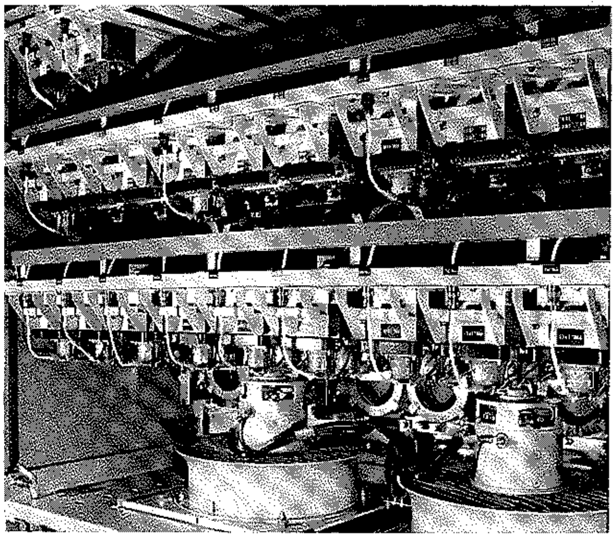


Fig. 3. — Thyristor racks (railroad type chopper) S.N.C.F. BB 7200.



During the complementary interval

$$0 = u_m + L\frac{-\Delta i_m}{(1-h)T}.$$

From these equations one obtains

$$\boxed{u_m = h \, . \, E.}$$

If i_1 is the current passing through the line, this current having a mean value equal to i_h, then

$$i_1 \, . \, E = u_m \, . \, i_m \, ,$$

$$i_1 \, . \, E = h \, . \, E \, . \, i_m \, ,$$

$$\boxed{i_1 = h \, . \, i_m \, .}$$

VOLTAGE-INCREASING CHOPPER BRAKING MODE OPERATION

The operational principle is shown in Figure 4.

The main relations are deduced from those given above

$$u_g = E - h \, . \, E = (1-h)E,$$

$$i_1 \, . \, E = u_g \, . \, i_g \, ,$$

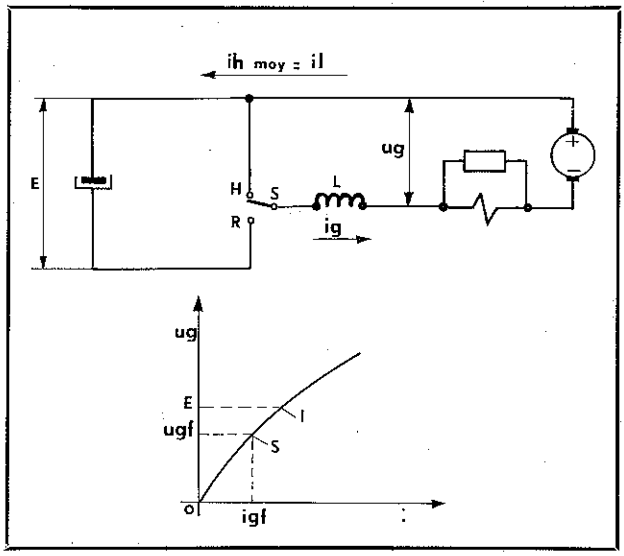
$$i_1 \, . \, E = (1-h)E \, . \, i_g \, ,$$

$$\boxed{i_1 = (1-h)\, i_g \, .}$$

These are the same relations as those for voltage reduction, except that h is replaced by (1—h).

However, the circuit shown in Figure 4 requires some additional explanations. The generator, self-excited in this example, delivers to the source E across the chopper. It is a fact that delivery of a self-excited generator to a fixed voltage source E is unstable (point I unstable in Figure 4).

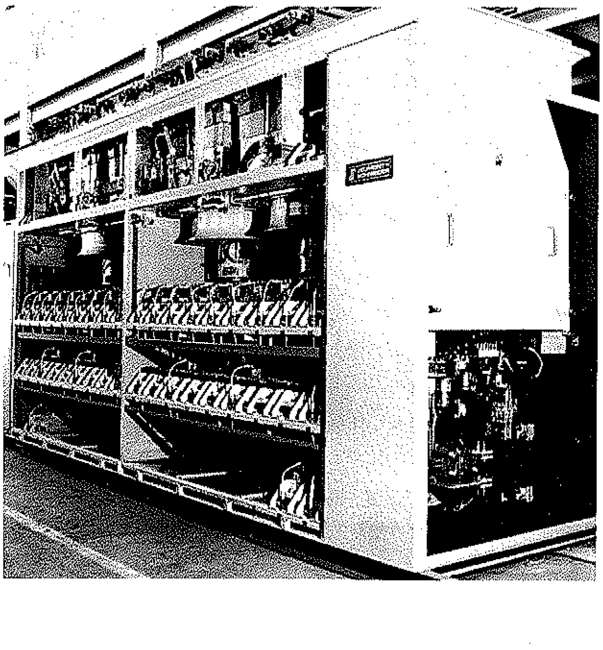
Fig. 4



The chopper now permits stable delivery, provided the working point S is situated between points O and I:

- when the chopper is conducting (change-over switch on *H*), it opposes a zero voltage to the combination generator/reactor *L*. The working point S moves toward I;
- when the chopper is non-conducting (change-over switch on *R*), the voltage *E*, higher than u_g, is opposed to the combination generator/reactor. The working point S moves towards O. It is thus seen that by an appropriate adjustment of the conduction ratio *h*, the point S can be maintained where desired. The only requirement is that the chopper should be fast enough as compared with the current rise time.

Fig. 5. — Railroad type chopper. General view: thyristor racks, blowers and on the right, circuit breaker type HRKS (S.N.C.F. BB 7200).



For dynamic braking, instead of source *E*, we use a braking resistance Rh, such that

$$\mathrm{Rh}\,(i_h\,\mathrm{max})=E.$$

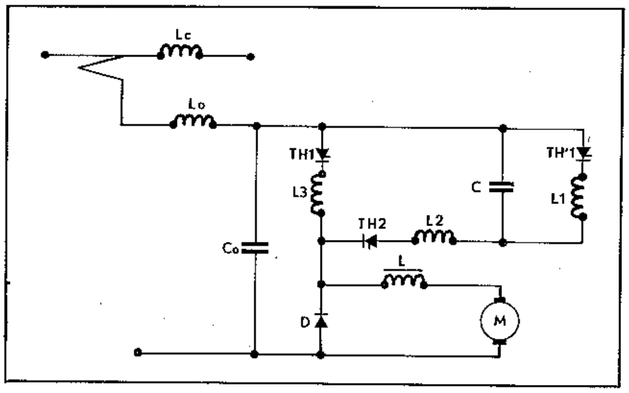
The chopper thus produces the braking effect at maximum current, as if it were regenerating on *E*, and at lower currents, as if it were regenerating on a source with lower voltage.

CIRCUIT CHARACTERISTICS

A TYPICAL CHOPPER CIRCUIT

One of the most advantageous and widely used circuits is shown in Figure 6. There are many circuits which offer interesting advantages, the choice amongst them depending on the particulars of the problem.

Fig. 6. — Basic chopper circuit.



The basic chopper circuit (*Fig.* 6) differs from the schematic circuits (*Figs.* 2 and 4) in the following details:

- contact R is replaced by free-wheeling diode D;
- contact H is replaced by branch Th 1, L 3, and by the turn-off system Th' 1, L 1, C, L 2, Th 2;
- a filter L_0 C_0 is inserted between chopper and source. In railroad electric traction, the overhead line (or third rail) introduces a variable reactor L_c between the source and the propulsion unit. In order to restore the low impedance source required for the chopper, a capacitor C_0 is inserted as close to it as possible. L_0 is added in order to reduce the dependence of the period

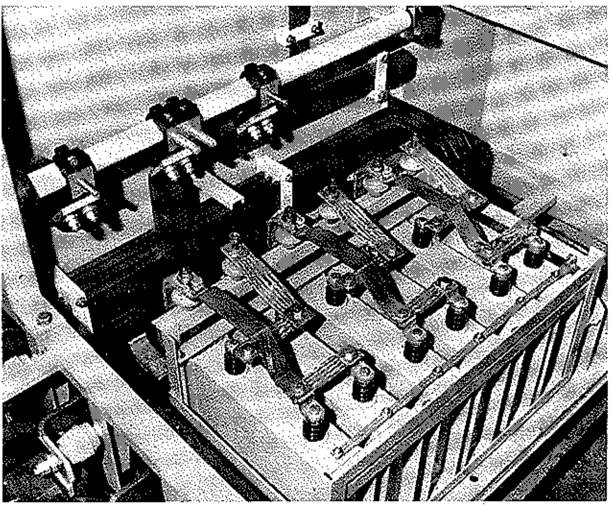
$$[T=2\pi\sqrt{(L_c+L_0)C_0}\,].$$

of the circuit L_c L_0 C_0 on L_c.

INTERLACED CHOPPERS

The circuit depicted in Figure 8 shows the principle of interlacing which is often used.

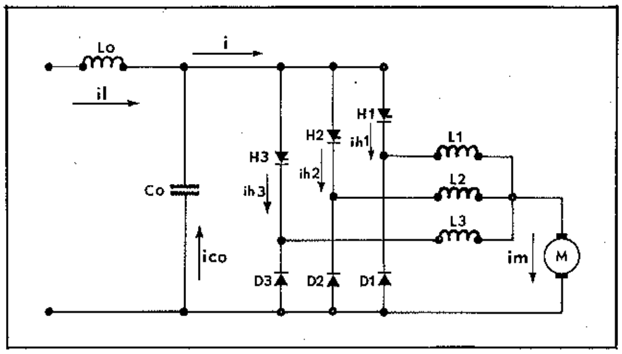
Fig. 7. — Turn-off capacitor.



This arrangement permits to divide by the cube of the number of phases (q^3) the amplitude of the a. c. current introduced into the line by the chopper.

Motor current ripple is also reduced but this is less important since the traction motors withstand it well.

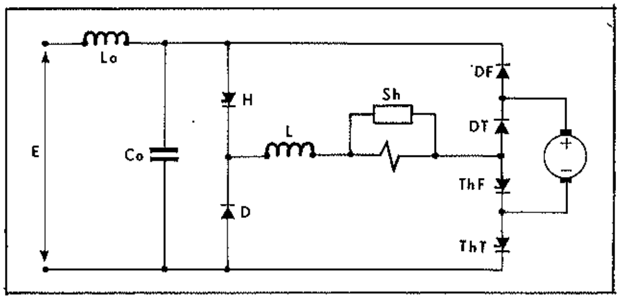
Fig. 8. — Interlacing of three choppers.



TRACTION-BRAKING STATIC COMMUTATION

The circuit in Figure 9 shows how a chopper may be switched from the traction to the braking mode by means of a static switching unit.

Fig. 9



In the "traction" mode, the current flows through the diode DT and the thyristor Th T. In the "braking" mode, the current flows through Th F and DF.

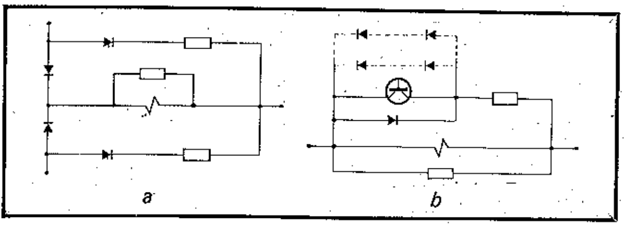
The thyristors Th T and Th F are not of the "fast" type. The chopper itself turns them off by cutting off the current.

FIELD WEAKENING

Weakening the field of a motor permits a large extension of the useable range of its speed-torque curve.

Field weakening is used in traction and in braking modes. In both cases, it is advantageous to control it in a continuously variable mode. This may be obtained through systems of the chopper type operating both in traction and in braking and completely progressive modes.

Fig. 10. — Field weakening by means of: *a*) transistors, *b*) thyristors.



ELECTRIC BRAKING

Dynamic braking

Dynamic braking is easily obtained by means of a single resistance (*see* paragraph "Voltage-Increasing Chopper. Braking Mode Operation").

This type of braking is most often used by locomotives on main lines. Generally, except in the case of very long down-gradients, braking energy is low as compared with traction energy and it is not profitable to recover it.

Regenerative braking

Regeneration is worthwhile in urban and suburban networks. Regeneration reduces the load on the mechanical brakes as is the case of dynamic braking but in addition, saves energy and reduces heating of the rolling stock, tunnels, and railroad stations.

On the other hand, the use of regenerative braking requires some changes in the concept of the combination "fixed installation-rolling stock".

It is therefore useful to examine these features from the following viewpoints:

- energy;
- mechanical braking;
- supply network.

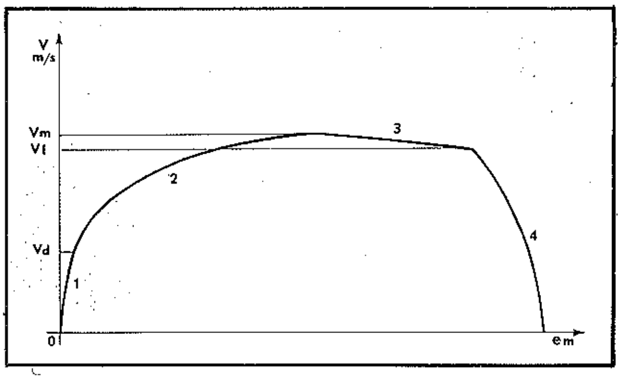
Energy balance

Quantitative determination of the energy saving leads to quite different results depending on the gradient of the track, distance between stops, performance, supply network...

The balance concerning a suburban train or a subway train on a level stretch between two stations (*Fig.* 11), may be calculated approximately and simply by the kinetic-energies method.

Fig. 11. — Speed v/s space diagram.

1, starting: 0 to V_d, motor speed (full current/full field); 2, build-up period of maximum speed: V_d to V_M, max speed; 3, coasting: V_M to V_F, braking speed; 4, braking: V_F to 0.



If the inertial mass of a train, including the contribution of the rotating masses, is M, the kinetic energies E_d, E_M, E_F at the respective velocities V_d, V_M, V_F are

$$E_d=\frac{1}{2}M(V_d)^2,$$

$$E_M=\frac{1}{2}M(V_M)^2,$$

$$E_F=\frac{1}{2}M(V_F)^2,$$

and the electrical energies E_{Dd} and E_{DM} required from the network to supply the train with the energies E_d and E_M are

$$E_{Dd}=\frac{E_d}{r},$$

$$E_{DM}=\frac{E_M}{r},$$

r being the global efficiency of transformation of the electric energy into kinetic energy taking into account all losses (electric, rolling, air resistance, transmission, etc.).

If E_f is the braking energy by dissipation (mechanical and/or dynamic), it is convenient to define the factor

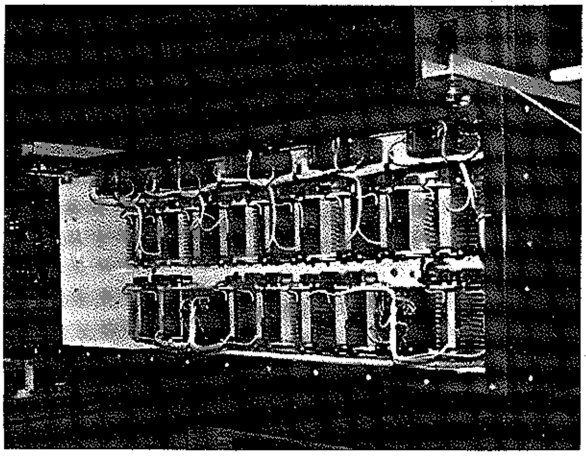
$$f=\frac{E_f}{E_F}.$$

Where:

$f=0$, if the entire recoverable energy is regenerated;

$f=1$, if the entire energy is dissipated.

Fig. 12. — Chopper unit for rapid transit applications (Montréal Metro).



In the numerical example given further on:

- in the case of the chopper, the energy returned to the line is

$$E_{RF}=r\,.\,E_f(1-f)\qquad \text{where}\quad f=0.33;$$

- in the case of standard electro-mechanical equipment without dynamic braking, dissipation in the mechanical brakes is

$$E_f=f\,.\,E_F\qquad \text{where}\quad f=0.82.$$

(The remaining braking energy, i. e in this case 0 . 18 E_F, is dissipated by resistance to movement.)

Energy consumption C_c of conventional equipment is

$$C_c=E_{DM}+E_{Rh}.$$

(E_{Rh}, the energy dissipated in a starting rheostat, equals E_{Dd} if there are no changes in motor coupling but equals $E_{Dd}/2$ if series coupling is followed by parallel coupling as is most often the case.)

Energy consumption C_H of equipment with chopper is

$$C_H=E_{DM}-E_{RF}.$$

Fig. 13. — One of the new Montreal Metro railcars equipped with Jeumont-Schneider regenerating choppers.

Numerical example

		Standard Electro-Mechanical Equipment		Chopper Equipment	
Mass M r f	(f)	190 0.7 0.82		194 0.685 1/3	
V_M	(m/s)	30	25	30	25
V_F	(m/s)	28	23	28	23
V_d	(m/s)	12	12	12	12
E_{DM}	(MJ)	122	85	127.5	88.5
E_{Rh}	(MJ)	10	10	0	0
E_{RF}	(MJ)	0	0	35	23.5
E_F	(MJ)	61	41	17.5	11.5
Consumption					
C_c	(MJ)	132	95	–	–
C_H	(MJ)	–	–	92.5	65
$\frac{C_H}{C_c} =$		0.7 for $V_M = 30$ m/sec. 0.685 for $V_M = 25$ m/sec.			

Such a method of calculation is often a useful preliminary to the exact and complete calculations which take into account the gradients, number of starts, slow-downs, coastings and steady-speeds.

It is possible with a computer to simulate the operation of a line. In this way one can also calculate power consumption of trains and substations, the energies and power handled by the mechanical brakes and one can dimension the rectifying and converting stations, certain line equipment (impedance bonds, circuit breakers, etc.) (*see* paragraph "Supply Network And Regeneration": *Fig.* 14 results from such a calculation).

Stresses in mechanical brakes

In the above mechanical example, we chose $f=1/3$, which means that the mechanical brakes dissipate one third of the kinetic energy in the form of heat. This is often the case for the following reasons:

- when a train consists of railcars and trailers and when a certain amount of mechanical braking is left on the trailers;
- when it is not desirable to overdimension the railcar and its equipment in order to achieve fully electrical braking from high speeds;
- when the supply network is not provided with converters and consumption is too low to absorb the regenerable energy.

Generally speaking, the coefficient f is the result of a compromise between the regenerated energy, the capacity of the motors and other onboard equipment, the stress on the mechanical brake system and the supply equipment of the line.

The unregenerated energy may be dissipated through resistor grids (dynamic braking) or through mechanical braking.

It is important to note that brake-shoe wear can be very low if the energy and the power to be dissipated are below certain thresholds. Indeed, brake-shoe wear is not at all proportional to the stress applied. Wear increases much faster. It is obvious for instance that if stress leads to fusion or decomposition temperatures, wear is very fast.

That is the reason why regeneration, even if partial, may radically reduce brake-shoe wear.

Supply network and regeneration

If the choppers were to be used in motoring mode only, this would slightly advantage the network:

- somewhat less energy to be supplied;
- slightly weaker voltage drops at starting;
- easy current collecting at the beginning of starting since line current is very weak;
- easier protection by di/dt.

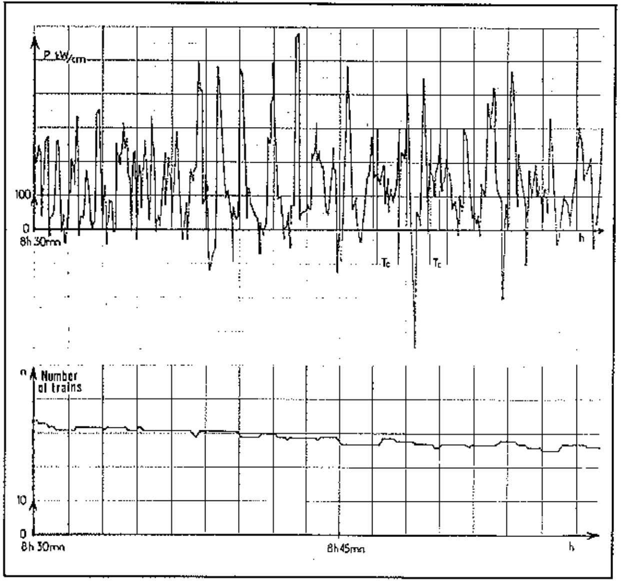
Regeneration indeed offers both important advantages and new constraints. The advantages are based on the fact that the supplied energy is significantly reduced and that the average voltage is increased.

The constraints originate from the fact that the energy consumptions and regeneration are seldom simultaneous except during very heavy traffic (*Fig.* 14).

Fig. 14. — Diagram of Current v/s Time in a sub-station equipped with rectifier and converter.

The currents supplied by the rectifier are shown above the time axis and the currents picked up from the line by the converter are shown below the time axis. During the time intervals marked T_c (compensation intervals), the regenerated currents exist simultaneously with the traction currents. The resulting current is then moderate and nearly constant.

In this example, 30 trains are simultaneously running on a 30 km line. The substations are separated by 2 km intervals approximately.



If in a given substation the supplied current tends to become negative because the regenerated currents prevail over the traction currents, one must:

— either add a converter to the rectifier of this substation;
— or provide the trains with a system which at those moments limits regeneration.

This last process may be used alone: braking energy is then more or less regenerated according to traffic density.

The first process is more satisfactory: braking energy is always optimally regenerated and the maximum network voltage is rather well defined. But in this case, the onboard system which limits regeneration is still required in order to operate when a converter is disconnected.

The chopper from the operator's point of view

The chopper is thus very different from the conventional equipment. Operation in the regenerative mode involves the provision of special devices on the train and, at times, the erection of converter plants on the network.

The operator will nevertheless observe that the advantages afforded are numerous as far as the network, train driving, protection and maintenance are concerned.

THE CURRENT CHOPPER AND ITS SUPPLY NETWORK

The advantages offered to the network by the chopper may be classified according to two characteristics: energy saving and weak line currents at low train speeds.

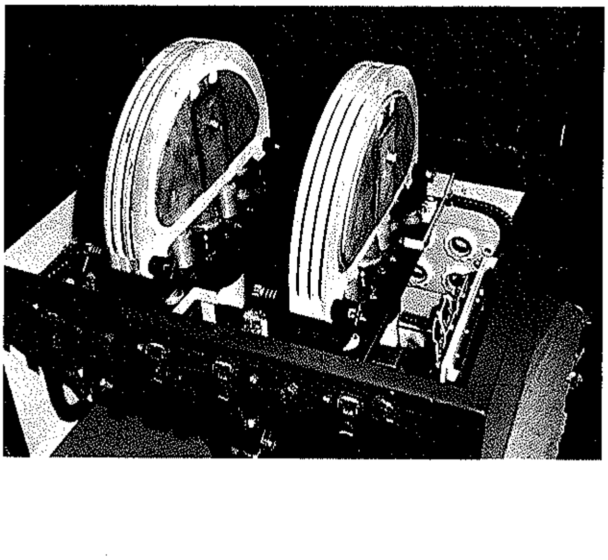
Energy saving results in:

— better use of an existing network which can admit a larger number of trains or provide better performance through higher line voltage (and for new networks, more optimally dimensioned installations);

— a reduction in the amount of heat dissipated in the trains, tracks and stations. While this is of greater importance for the networks in tunnels than for outdoor networks, it should be kept in mind that the mechanical braking energy absorbed mainly by the wheels is partially returned into the stations;

— a reduction in operation costs which is by no means negligible.

Fig. 15. — Circuit breaker box for rapid transit application comprising two CRA 1000 type units (one for braking, one for motoring) (Montreal Metro).



The weak line current at low velocities:

— facilitates easy current collection without deterioration at contact points and,

— in case of simultaneous breakdown of several substations, keeps the trains running at reduced speed but under full tractive effort if necessary (e. g. along up-gradients).

TRAIN DRIVING

Driving is improved by fast and smooth controls which offer:

— easy manoeuvers at all speeds and especially in coupling operations;

— easy running at constant speed, both manual and automatic ("imposed speed" or automatic control) and without causing fatigue to the equipment;

— instant traction/braking switchovers and vice versa;

— better wheel/track adhesion due to constant or progressively variable tractive effort;

— fast intervention in the event of wheel slip to restore normal adhesion.

The fact that there is no starting rheostat constitutes an additional advantage for driving: in the case of a heavily loaded train stopped on an up-gradient, starting may be extremely slow. The long starting time affects neither the chopper nor the motors but may severely damage a rheostat.

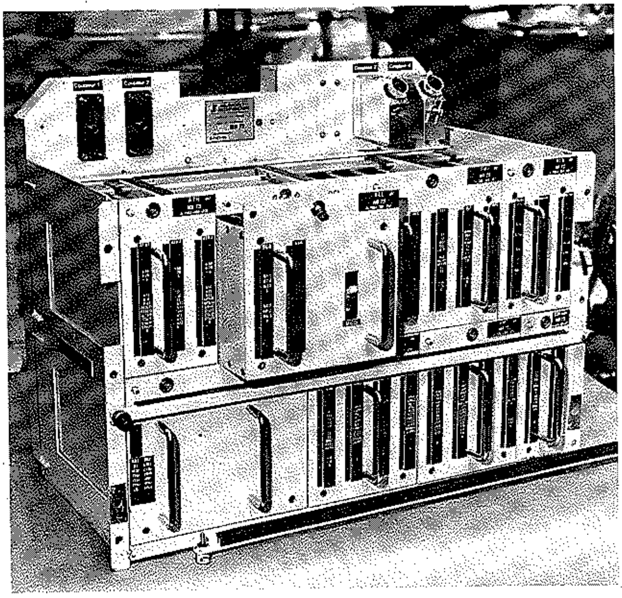
Finally, the combination of these properties facilitates automatic operation. It can be simply designed since it can require, without any component wear, frequent changes in traction or braking effort, frequent traction/braking switchovers, operation close to the adhesion limit, accurate speed adjustments for all effort values. Accurate stop (target shooting) is made easy.

PROTECTION PROVIDED BY THE CHOPPER

The chopper permits improved supply network protection. As a matter of fact, if the network supplies only the choppers, rapid current variations will not occur during normal operation.

Then, it is possible to place quite sensitive sensors in *di/dt* and to detect short circuits in this way even if they occur far from the substations.

Fig. 16. — Chopper control rack for rapid transit applications (Montreal Metro).



The chopper also improves protection on the trains:

- it protects all components connected at its filter output from network transient overvoltage;
- in case of breakdown of the circuits supplied by the chopper (smoothing reactor, motor, traction/braking switchovers) rapid current-detection of the chopper causes the immediate turn-off of the chopper and if necessary, actuates the circuit breaker.

MAINTENANCE

Maintenance of mechanical components

The general lowering of mechanical stresses reduces wear and increases the service life of certain components and will subsequently justify longer intervals between the respective maintenance operations. The immediate gain concerning maintenance is obvious. It resides in savings related to the replacement of brake shoes when the chopper is provided with electrical braking.

Maintenance of electro-mechanical components

The chopper of our design contains only a few electromechanical components. They are: a reversing switch, two circuit breakers and, in some cases, isolating switches.

During normal operation, these devices never interrupt any current. In the case of faulty operation, it is the chopper itself which interrupts the current. Seldom is the circuit breaker involved.

Under these circumstances, maintenance is reduced to checking at fairly long intervals the proper working condition of these elements.

Maintenance of electrical components

The electrical components include reactors, capacitors, power semi-conductors and for weak current circuits, semi-conductors with their associated elements. None of these parts is subject to progressive wear. On the contrary, mechanical and electrical failures occur without prior warning. Taking into account the known failure rates, it is possible to evaluate, at least approximately, the Mean Time Between Failures (M.T.B.F.).

Since the components are so designed that this time is compatible with operational use, there is no need for preventive maintenance. It is enough to repair the defects when they occur.

However, air cooling paths are subject to continuous fouling and periodic cleaning is required. During the cleaning operations, visual inspection of all the parts is carried out.

Checking the chopper

Maintenance which has been briefly described above should be completed by a quite simple systematic checking of chopper operation.

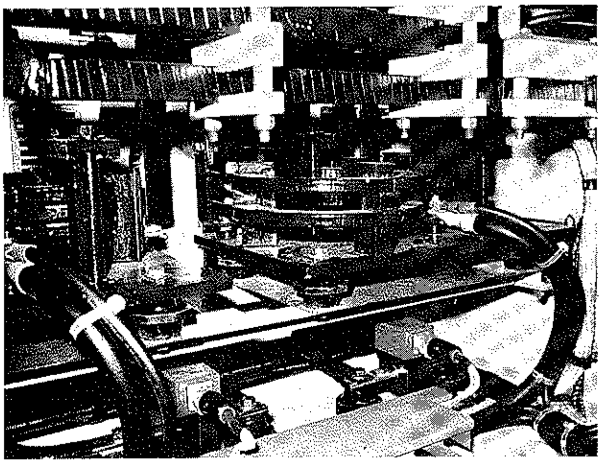
For this purpose, the Jeumont-Schneider choppers include extra circuits which permit through a very simple actuation known as "no-load test", to perform a thorough checking of the whole system.

Checking may be carried out by the driver before leaving the depot. All he need do is to actuate the "no-load test" key, make sure that a light blinks, give any traction command (the train remaining stationary of course) and ascertain that the light goes out. These operations take only a few seconds and yet guarantee that the vital functions of the chopper are sound.

During the checking-out procedures at the shop, fault localisation on the train itself is made easy by the "no-load test" installation, test terminals and warning lights.

Lastly, the complex electronic sub-assemblies (circuit cards and racks) can be disconnected and separately tested with special equipment.

Fig. 17. — Set of phase reactors (Montreal Metro).



Signalling and tele-transmission v/s traction equipment

Conventional traction

If the conventional traction systems do not interfere significantly with the weak current systems, the reason is that arrangements have been made to ensure their coexistence. More often than not, the weak current systems have been designed to accomodate existing traction systems.

The supply network produces d. c. current by rectifying (in an hexaphase or double hexaphase rectifier) an a. c. current of industrial frequency (50 or 60 Hz).

This current is distributed by the contact line and the track. It is liable to influence the track circuits of the signalling system and tele-transmission lines parallel to the track by conduction or induction.

The spectrum mainly includes one of the following frequencies (50 or 60 Hz) × (6 or 12), i. e., 300 or 360 Hz or 600 or 720 Hz but may include as well any multiple of 50 or 60 Hz.

All present and future signalling and tele-transmission systems for d. c. current networks are designed to operate despite these frequencies.

Open air lines compensated for by transposition are influenced at a mostly acceptable level however.

Underground transmission cables offer a large immunity and are generally not sensitive to interferences.

Regarding track circuits, if they are of the "frequency type", they obviously use frequencies other than those of the supply network spectrum. Moreover, the present trend is to modulate these frequencies.

Among the other types of track circuits, the Jeumont-Schneider high-voltage impulse track circuits offer a large immunity to interference. This immunity is due to the shape of the impulse (aperiodic and asymmetrical) with very high instantaneous power: several kilowatts at the peak. That is the reason why this type of track circuit is compatible with all traction systems either conventional or modern.

To this day, Jeumont-Schneider has installed more than 45,000 track circuits of this type all over the world. This success is not due only to their large immunity to interference:

- *"shunting" is ensured by the high voltage even for light vehicles and dirty tracks;*
- *the repetition interval of the impulses is used to transmit information on board (e. g. cab signal).*

Modern traction

Principles

Choppers are designed as all modern traction systems in such a way that weak-current systems which are already compatible with conventional electric traction can be easily adapted:

- the operating frequencies of the chopper are chosen in such a way that the spectrum of its line current (and also of the voltages it induces) are included within the frequencies already existing in the network (no additional spectral component is produced);
- by means of the input filter, of phase interlacing and careful wiring and shielding, the amplitude of the chopper spectral components is so adjusted relatively to other existing components that no additional trouble will result.

In other words, the chopper noise disappears into the noise of the existing system.

The implementation of these principles has proved to be quite simple. All one need do is:

- not to try to operate the chopper at variable frequency.

  Operating at variable frequency implies reserving a large spectrum-band entirely for the chopper. Now, the regular signals and tele-transmissions use the same band and, as far as we know, the experimental choppers working at variable frequency always interfered with them. These experiments led to the belief that the chopper was a powerful source of interferences. Yet when well selected fixed frequencies are used, the chopper is extremely unobtrusive;
- to select a fixed frequency for normal operation (generally 300 or 360 Hz) so that the chopper spectrum will be included in the spectrum already present in the network;
- to select in the same manner a few lower frequencies which are also fixed, to facilitate fine adjustment (as required with low speeds and weak currents especially at starting);
- to make sure that the chopper input filter and the number of phases determined according to different criteria, ensure a sufficient reduction of the spectrum component amplitudes.

A.C. Components in the current line

The following numerical example shows the influence of the filter and of the number of phases on the reduction of certain spectrum components.

Let us assume a network supplying a d. c. current obtained by rectifying the 50 Hz industrial current by means of hexaphase rectifiers. The rectified voltage U has a slight ripple whose main component at 300 Hz has a peak amplitude of 5% of U approximately.

Conventional equipment whose motors are connected directly into the line and take a d. c. current i_m, behaves like a resistance $R = U/i_m$ and will cause an a. c. component i_a to circulate into the line at 300 Hz having a peak amplitude of about 5% i_m.

Similar equipment provided with choppers will circulate much weaker currents.

To demonstrate this, it is convenient to analyze separately the currents produced by the chopper and those produced by the substation.

Currents produced by the chopper

The general circuit is that of interlaced choppers. The operating chopper ($0<h<1$) produces a current ripple in the line with a frequency $q.f$ (where q = number of phases, f = operating frequency of each phase).

Let i_1 $(q.f)$ be the peak value of this a. c. current in the line

$$i_1(q.f)=\frac{i_m}{16 L_0 C_0 q^3 f^2}\times A,$$

where A = positive values of $(qh—k)$ $[1—(qh—k)]$, with k an integer such that

$$0\leqq k\leqq q-1.$$

Example 1:

$$i_m=1{,}200\,\mathrm{A},$$
$$L_0 C_0=16\times10^{-6},$$
$$q=2,$$
$$f=300\,\mathrm{Hz},$$
$$A=\frac{1}{4}$$

(maximum value obtained for $h=1/4$, $k=0$ or $h=3/4$, $k=1$) whence i_1 (600) = 1.6 A, or 0.14% of i_m, which is negligible.

Example 2:

This is the previous case but with one phase missing and a current of 600 A ($q=1$, $i_m=600$ A), whence i_1 (300) = 6.5 A, or 1% of i_m, which is about 5 times weaker than the current at 300 Hz which conventional equipment would allow to circulate.

It is also possible to calculate the a. c. components produced by the chopper when it operates at lower frequencies during starting. The frequency influence ($1/f^2$) tends to raise the a. c. current but since the chopper operates with very low h values, it is partially compensated for. In practice, the a. c. component may reach 2 or 3% i_m which is not troublesome even during extended manoeuvering.

Current produced by the 300-Hz component of the voltage supplied by sub-station

Z_h represents the motor impedance as seen across the chopper. It is a complex impedance being a function of the load conditions. Let us determine the resultant impedance taking into account L_0 and C_0. Let us find its minimum value.

Fig. 18. — General diagram of a sub-station supplying a chopper.

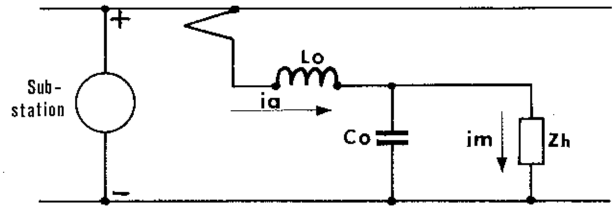


Fig. 19. — BB 7200 class 1,500 V d. c.-4,400 kW electric locomotive, EU 4500 C1 series, designed with dynamically braked monomotor trucks. Maximum speed: 180 km/hr. (112 mph). Maximum speed reverse service: 160 km/hr. (100 mph)

Using the numerical values from the previous examples, we obtain impedances at 300 Hz, close to 6 Ω, i.e. approximately $L_0\,\omega$.

With the 300 Hz component being 5% of U the current at 300 Hz for $U = 750$ V and $R = 6\ \Omega$ will be:

$$i_1 = \frac{5.750}{100.6} = 6.25\ \text{A}.$$

For the motor currents under consideration (1,200 and 600 A), this a.c. current is only 0.5 and 1%, i.e. much weaker than with conventional equipment.

Similarly, we can calculate the impedance represented by a chopper and its filter at 50 Hz. It is relatively weak but is in this case acceptable because the only system which might be disturbed (signalling at 50 Hz) should be given up for new installations. For lines still equipped with such systems, the substation is sometimes the 50 Hz voltage source and should be provided with the necessary impedance to reduce the current at this frequency.

CONCLUSION

The future of choppers

Choppers have been in use in railroad traction for the past ten years only. Nevertheless, they replace conventional equipment in most applications since railroad operators already prefer them.

Now, the use of the chopper creates new conditions which lead to a revised concept of motors and supply network in order to obtain better performances.

Further progress may therefore be expected.

Such progress will confirm the advantages already obtained and it should ward off rival systems, if any, for a long time.

Jeumont-Schneider references the world over

S.N.C.F.

Series choppers are in operation on:

- a Z 7001 railcar, 1,500 V-550 kW, dynamic braking (1974);
- a BB 7003 locomotive, 1,500 V-4,400 kW, dynamic braking (1974);
- 260 BB 7200 locomotives, 1,500 V-4,400 kW and BB 22200 locomotives, dual current, 1,500 V-25 kV-4,400 kW, dynamic braking supplied since 1976 and until 1980.

R.A.T.P. (Paris Metro)

Following experiments carried out on 4 MP 59 type railcars in 1971, choppers will be used on:

- railcars of type MF 77, 750 V-450 kW, regenerative braking.

600 chopper-equipped units will be supplied between 1977 and 1982.

Montreal Metro

Following tests in 1972 on rubber tired trainsets, choppers will be used on:

- railcars 750 V-520 kW, regenerative braking.

  282 railcars will be equipped with choppers, 18 of which to be supplied by Jeumont-Schneider and 264 manufactured by Canron (Canada) under Jeumont-Schneider licence.

Mexico-City Metro

- Trainsets made up of 3 trailers and 6 trainsets equipped with 750 V-520 kW choppers—regenerative braking—will be operating in 1977.

F.E.P.A.S.A. (Brazilian Railroads)

- 100 trainsets equipped with 3,000 V-900 kW choppers—regenerative braking—will be operating in 1978.

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