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École d'Ingénieurs de l'Université d'Orléans

Labwork

3-PHASE TRANSFORMER

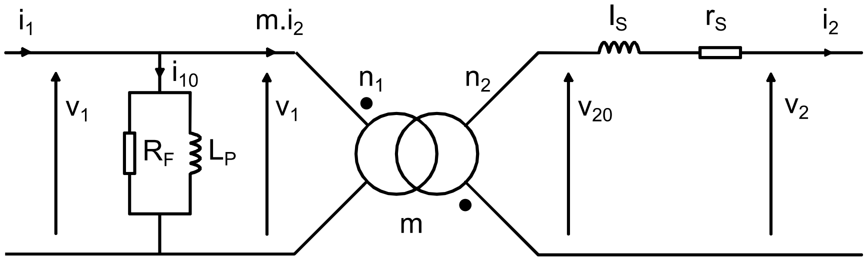
M1 AESM
Electrical Engineering

PW - STUDY OF THE THREE-PHASE TRANSFORMER

The objective of this labwork is to determine the elements of the equivalent diagram and to note the electrical characteristics of a three-phase transformer **(primary: 3 x 250V, secondary: 6 x 63V).** The apparent power of the transformer studied is **4 kVA.**

Reminders about the single-phase transformer

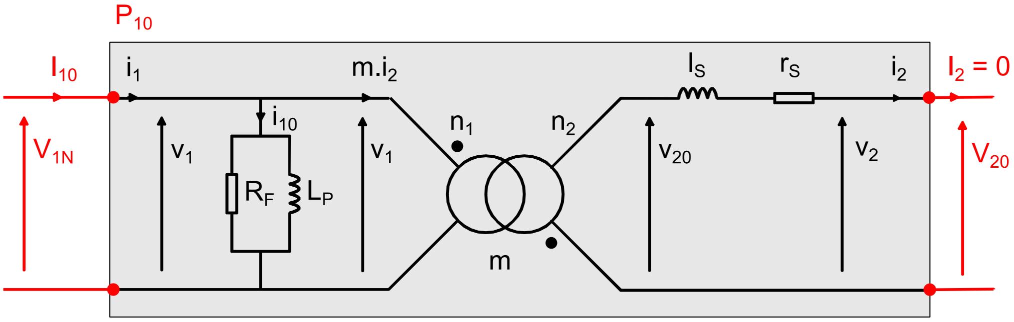
Equivalent single-phase Kapp's secondary model



$$m = \frac{n_2}{n_1} = \frac{V_{20}}{V_1} \cong \frac{I_1}{I_2} \qquad r_S = r_2 + m^2.r_1 \qquad l_S = l_2 + m^2.l_1$$

Determining the Kapp scheme

No-load test



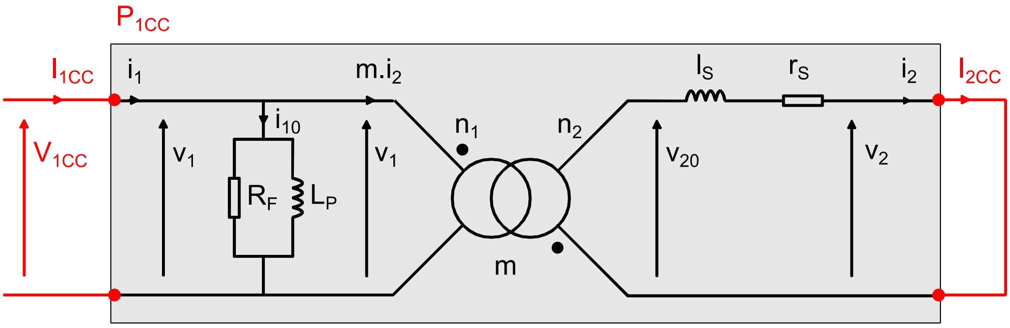
Transformer supplied under rated voltage: V_{1N} and secondary not charged: $I_2 = 0$

Measured quantities: V_{1N}, I_{10}, V_{20} and P_{10} (iron losses of the transformer)

$$R_F = \frac{V_{1N}^2}{P_{10}} \qquad X_P = L_P.\omega = \frac{V_{1N}^2}{Q_{10}} \qquad m = \frac{V_{20}}{V_1}$$

with $Q_{10} = \sqrt{(V_{1N}.I_{10})^2 - P_{10}^2}$

Short-circuit test



Transformer powered under reduced voltage: V_{1CC}

Short-circuit secondary loaded to its nominal value: $I_{2CC} = I_{2N}$

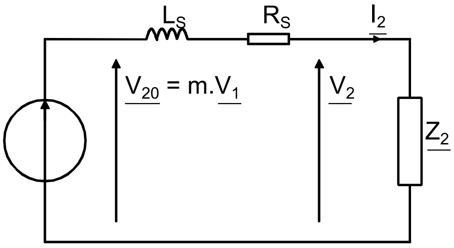
Measured quantities: V_{1CC}, I_{1CC}, $I_{2CC} = I_{2N}$ and P_{1CC} (copper losses of the transformer)

$$\boldsymbol{R_S = \frac{P_{1CC}}{I_{2CC}^2}}$$

$$\boldsymbol{X_S = L_S.\omega = \frac{Q_{1CC}}{I_{2CC}^2}}$$

with $Q_{1CC} = \sqrt{(V_{1CC}.I_{1CC})^2 - P_{1CC}^2}$

Exploiting the Kapp schema



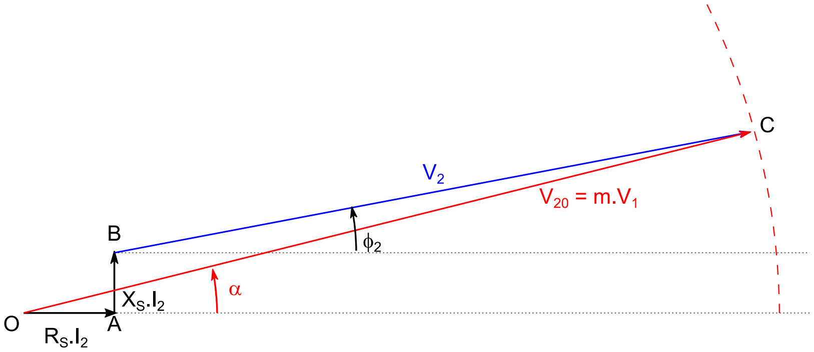
Equivalent diagram of the transformer under load brought back to the secondary

$$\boldsymbol{\underline{V_{20}} = m.\underline{V_1} = (R_S + jX_S).m.\underline{I_2} + \underline{V_2}}$$

Voltage drop

Triangle de Kapp

- Inductive load: $\varphi_2 > 0$



$$\boldsymbol{\Delta V_2 \approx R_S.I_2 \cos\varphi_2 + X_S.I_2.\sin\varphi_2}$$

Yield

$$\boldsymbol{\eta = \frac{V_2.I_2.\cos\varphi_2}{V_2.I_2.\cos\varphi_2 + R_S.I_2^2 + P_{Fer}}}$$

Iron losses: unladen test, P_{10}

Optimal current I_2:

- $\eta = \frac{V_2.\cos\varphi_2}{V_2.\cos\varphi_2 + R_S.I_2 + \frac{P_{Fer}}{I_2}}$
- Maximum yield for: $R_S.I_{2Opt} = \frac{P_{Fer}}{I_{2Opt}}$

$$\boldsymbol{I_{2Opt} = \sqrt{\frac{P_{Fer}}{R_S}}}$$

The relationships given above concern a single-phase transformer.
They must be adapted for the three-phase transformer.

Part One: Written Preparation

1) Briefly **recall** the principle of operation of a transformer.
2) **Draw** the equivalent diagram of a single-phase element of the three-phase transformer. **Give** the physical meaning of each of the elements of the equivalent scheme.
3) The three-phase transformer studied consists of 3 linearwindings and 6 secondary windings. **Propose** the connection scheme to have a Yy0 coupling.
4) Usings characteristics and for a Yy0 coupling, **calculate:**
   - the transformation ratio,
   - the current named the primary,
   - the secondary rated current.

Part Two: Practical Activities

No-load test

For measurements, a network analyzer will be used. To increase the sensitivity of the current measurement, it is advised to wrap 6 turns around each amperemetric clamp of the network analyzer. Of course, the results will have to take this into account !

5) **Recall** the quantities measured during this test.
6) **Propose** a wiring diagram and a procedure to the teacher for this test.
7) **Visualize,** using the network analyzer, the currents in the 3 phases. **Conclude** on the validity of this test and the balance of the currents. **Relevate** the requested quantities.
8) **Calculate** the transformer transformation ratio for a Yy0 coupling, lavalue oftheelements, R_F and X_P, of the equivalent diagram of the transformer.
9) **Bring** a physical conclusion on the values of R_F and X_P.

Short-circuit test

Caution this test may lead to the destruction of the transformer. It must be performed under reduced voltage for a secondary current equal to its nominal value.

10) **Recall** the quantities measured during this test.
11) **Propose** a wiring diagram and a procedure to the teacher for this test.
12) **Relevate** the requested quantities.
13) **Calculate** the value of the R_S and X_S elements of the equivalent schema. **Bring** a physical conclusion on the values of R_S and X_S.

Predetermination of the electrical characteristic $V_2(I_2)$ of the transformer

14) From the relation of the approximate value of the voltage drop at the secondary and the values specific to the transformer studied, **plot** the theoretical characteristic $V_2(I_2)$, for I_2 varying from 0 to I_{2N}.

Predetermination of transformer performance characteristic

15) **Give** the expression of the efficiency of a three-phase transformer.

16) From the relation of the yield and the values specific to the transformer studied, **plot** the efficiency characteristic $\varphi(I_2)$, forI_2 varying from 0 to I_{2N}.

17) **Calculate** the value of the current for which the efficiency is maximum.

Transformer load test: resistive load

To carry out this load test, a resistive load plan connected to the transformer shall be used. The network analyzer will measure the quantities on the secondary of the transformer, a wattmetric clamp the quantities on the primary.

18) **Propose** a wiring diagram and a procedure to the teacher for this test.

19) By modifying the load of the transformer, **record** and **trace** the characteristics $V_2(I_2)$ and $\eta(I_2)$, for I_2 varying from 0 to I_{2N}.

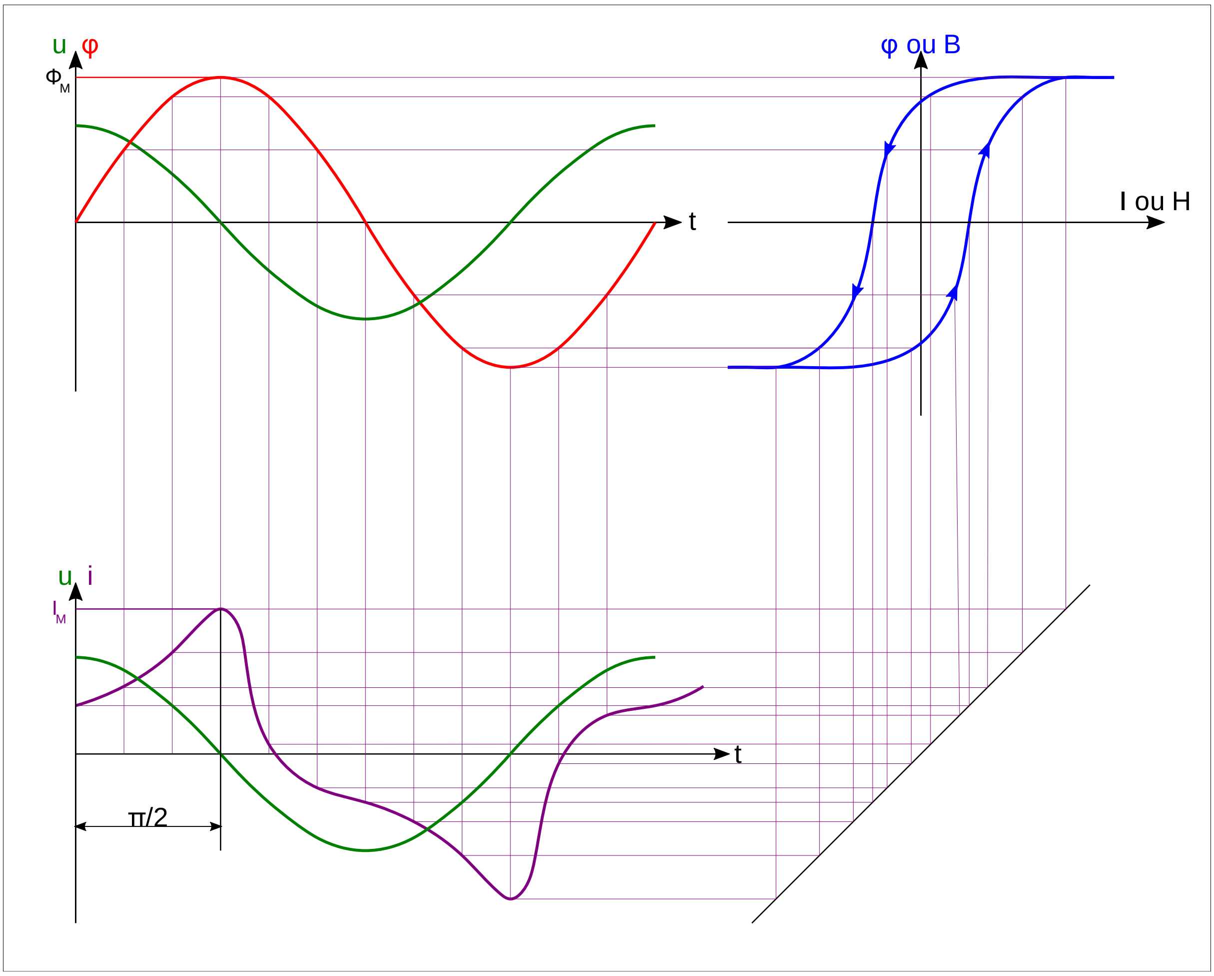
20) Comparing the measurements to the predeterminations, **conclude** on the correctness of the equivalent Kapp model.

Transformer load test: inductive load

The resistive load plane is associated with an inductive load. The desired power factor is 0.8.

21) **Propose** a wiring diagram and a procedure to the teacher for a test in charge with a current equal to the nominal current. **Perform** the test in the presence of the teacher.

22) **Compare** measurement to predetermination and **conclude** on the accuracy of Kapp's equivalent model.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Labwork

INDUCTION MOTOR

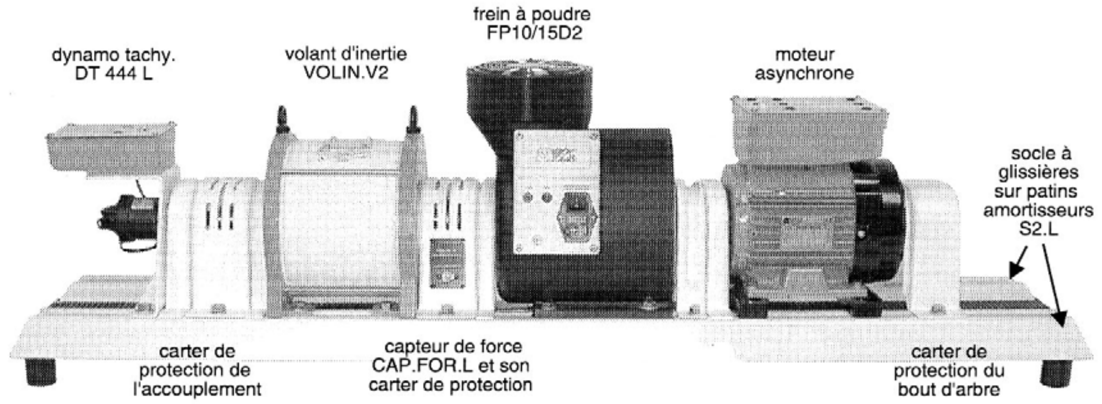
M1 AESM
Electrical Engineering

PW - ELECTROMECHANICAL STUDY OF AN ASYNCHRONOUS MOTOR

We want to check the **electromechanical characteristics** of an asynchronous motor mounted on a test bench and compare them with the values provided by the manufacturer on the plate and in its documentation.

To do this, several tests will be carried out to accurately determine the electromechanical characteristics of the motor.

PRESENTATION OF THE ENGINE BENCH



The **motor** is mounted on a **bench** with **several equipment**.

A **powder brake** is used to simulate the motor load. It is powered by the **"MODMECA" module**, which provides a direct voltage. The more this voltage is increased, the more the brake imposes a heavy load on the motor. **Be careful**, however, not to exceed the rated power of the motor.

A disengageable **flywheel** simulates a load with high inertia.

A **force sensor** measures the torque required by the brake. A **tachometric dynamo** measures the rotation speed of the bench.

DO NOT FORGET TO VENTILATE THE BRAKE AND POSSIBLY THE ENGINE.

Part One : Written Preparation

RESEARCH OF THE MANUFACTURER'S DATA AND PRELIMINARY CALCULATIONS

Q19) **LS90L-1.5kW** is the reference of the studied motor. **Note**, in the manufacturer's documentation (Appendix 1),

- the nominal power,
- the nominal speed,
- the nominal torque,
- the power factor at the nominal load,
- the motor supply voltage,
- the in-line current consumed by the motor in nominal operation,
- the motor efficiency in nominal operation.

Q20) **Check**, by calculation, the current and torque of the motor in nominal operation. **Calculate**, from the manufacturer's documentation, the current and torque of the motor at start-up.

Q21) **Determine**, by arguing, how the motor, star or triangle should be coupled to the conventional 3x400V - 50Hz three-phase network.

Q22) After reading Appendix 3, **justify** the use of a frequency inverter for an asynchronous motor. **Decompose**, through a simple diagram, a frequency inverter and **represent** the shape of the characteristic voltages in the inverter.

Q23) **Give** the conditions on the currents in the engine imposed by the Ferraris theorem. **Deduce** the shape of current and voltage in a motor powered by a frequency inverter.

Part Two: Practical Activities

NOMINAL AND NO-LOAD OPERATION

Q24) **Draw** a circuit diagram to measure the electrical power absorbed by the motor, the motor supply voltage and the current absorbed by the motor. An **MX200** clamp will be used. OFF VOLTAGE, **wire** the diagram. **Have the wiring validated by the teacher**.

Q25) **Take** the necessary measurements to determine the following quantities :

- For nominal motor operation : **current consumption**, **speed**, **power factor** and **efficiency**,
- For no-load motor operation : **current consumption**, **speed** and **power factor**.

Q26) On the report, **present** the measurements and calculations. **Comment** and **conclude** on the adequacy between the values recorded or calculated and those announced by the manufacturer.

YIELD CHARACTERISTIC

Q27) For 7 operating points, 25%, 37.5%, 50%, 62.5%, 75%, 87.5%, 100% of the nominal power,

- **record**, using a spreadsheet, the **mechanical power**, **torque**, **rotation speed**, **electrical power**;
- in real time and for each measurement, **calculate** the efficiency of the motor, **verify** that the mechanical power is the product of the torque and the angular velocity and **plot** the **yield characteristic** of the motor according to the ratio of useful power / nominal useful power.

Q28) **Comment** and **conclude** on the appearance of the curve and the adequacy between the values measured or calculated and those announced by the manufacturer.

DISPLAY OF THE STARTING CURRENT

In order to check the electromechanical characteristics at start-up, its current and speed during the start-up phase are displayed using an oscilloscope. A current probe is used for the current and a voltage probe for the tachometer dynamo.

Q29) **Draw** a circuit diagram allowing the simultaneous visualization of the starting current and the motor speed during the starting phase. **OFF VOLTAGE**, **wire** the diagram. **Have the wiring validated by the teacher.**

Q30) **Perform** one or more tests. **Print** or **save** the final oscillogram.

Q31) **Operate** the oscillogram by determining the RMS values of the current during the transient phase and during the established phase. **Determine** or evaluate the start-up time.

Q32) On the report, **present** the measurements and calculations. **Comment** and **conclude** on the adequacy between the values recorded or calculated and those announced by the manufacturer.

SPEED VARIATION

Drawing and wiring of the electrical diagram

Q33) **Draw** a electrical diagram allowing

- to supply a three-phase asynchronous motor from a frequency inverter,
- to visualize the voltage and current at the motor input,
- to measure the voltage delivered to the motor.

Q34) **OFF VOLTAGE**, **wire** the diagram. **Have the wiring validated by the teacher**.

Variable frequency test

Q35) Using the oscilloscope, **view** and **record** the voltage and current at the motor input for two frequencies (25 and 50 Hz). **Comment** and **conclude** on the adequacy between the shape planned for the preparation and those visualized.

Q36) For a supply frequency varying from 0 Hz and at the upper limit value, **read** the supply voltage "U" and **plot** characteristic U(f) at the inverter output. **Comment** on the appearance of the characteristic.

APPENDIX 1

Leroy Somer
Catalogue

Moteurs asynchrones triphasés fermés
Carter alliage aluminium LS
Caractéristiques électriques

E1 - Grilles de sélection : mono-vitesse

4 pôles
1500 min^{-1}

IP 55 - S1
Cl. F - ΔT 80 K

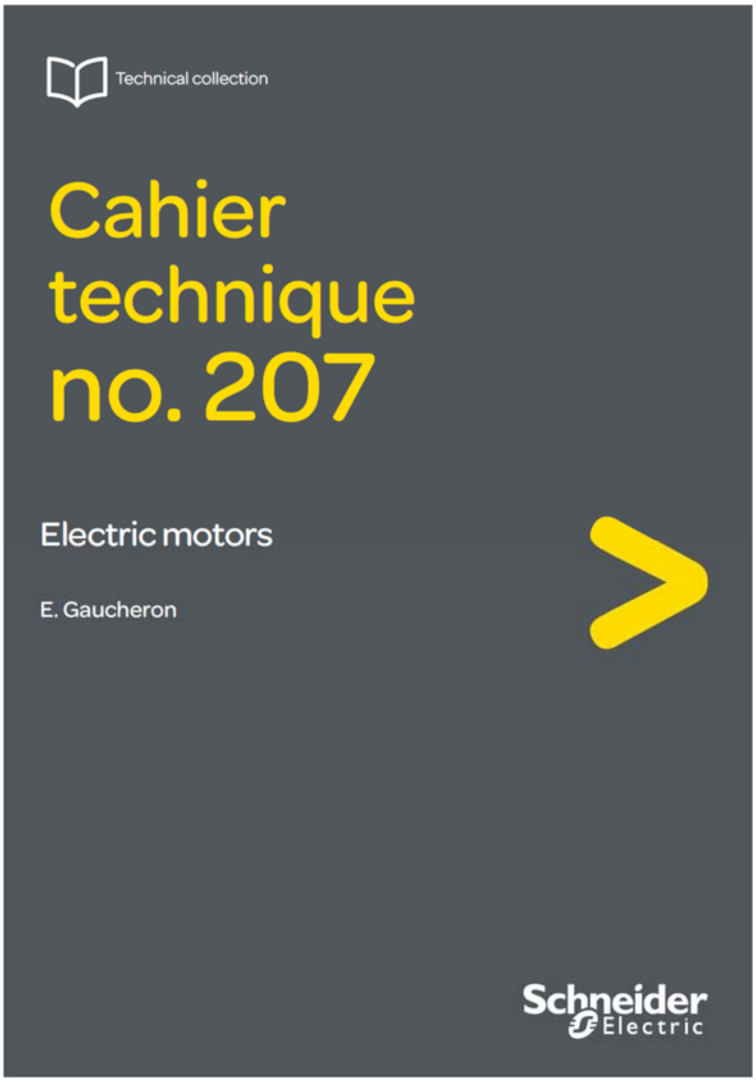
RÉSEAU Δ 230 / Y 400 V ou Δ 400 V **50 Hz**

	Puissance nominale à 50 Hz	Vitesse nominale	Couple nominal	Intensité nominale	Facteur de puissance			Rendement			Courant démarrage / Courant nominal	Couple démarrage / Couple nominal	Couple maximal / Couple nominal	Puissance apparente nominale	Courbe de couple*	Moment d'inertie	Masse
Type	P_N kW	N_N min^{-1}	C_N N.m	$I_{N (400V)}$ A	50 %	Cos φ 75 %	100 %	50 %	η 75 %	100 %	I_D / I_N	M_D / M_N	M_M / M_N	kVA_N	N°	J kg.m^2	IM B3 kg
LS 56 L	0,09	1400	0,6	0,39	0,42	0,52	0,60	42,8	49,6	55	3,2	2,8	2,8	0,27	2	0,00025	4
LS 63 M	0,12	1380	0,8	0,44	0,47	0,58	0,70	46,8	54	56	3,2	2,5	2,4	0,31	2	0,00035	4,8
LS 63 M	0,18	1390	1,2	0,64	0,44	0,55	0,65	51	58	62	3,7	2,7	2,7	0,45	2	0,00048	5
LS 71 L	0,25	1425	1,7	0,80	0,45	0,56	0,65	60	67	69	4,6	2,7	2,9	0,56	2	0,00068	6,4
LS 71 L	0,37	1420	2,5	1,06	0,47	0,59	0,70	66	72	72	4,9	2,4	2,8	0,73	2	0,00085	7,3
LS 71 L	0,55	1400	3,8	1,62	0,49	0,62	0,70	65	70	70	4,8	2,3	2,5	1,12	2	0,0011	8,3
LS 80 L	0,55	1410	3,8	1,42	0,55	0,68	0,76	62	69,3	73,4	4,5	2	2,3	1	7	0,0013	8,2
LS 80 L	0,75	1400	5,1	2,01	0,59	0,71	0,77	66	70	70	4,5	2	2,2	1,4	7	0,0018	9,3
LS 80 L	0,9	1425	6	2,44	0,54	0,67	0,73	70	73	73	5,8	3	3	1,6	6	0,0024	10,9
LS 90 S	1,1	1429	7,4	2,5	0,64	0,77	0,84	77,1	78,4	76,8	4,8	1,6	2	1,7	7	0,0026	11,5
LS 90 L	1,5	1428	10	3,4	0,60	0,74	0,82	77,5	79,4	78,5	5,3	1,8	2,3	2,3	7	0,0032	13,5
LS 90 L	1,8	1438	12	4	0,61	0,75	0,82	79	80,8	80,1	6	2,1	3,2	2,7	4	0,0037	15,2
LS 100 L	2,2	1436	14,7	4,8	0,59	0,73	0,81	79,8	81,5	81	5,9	2,1	2,5	3,4	7	0,0043	20
LS 100 L	3	1437	20,1	6,5	0,59	0,72	0,81	80,8	82,6	82,6	6	2,5	2,8	4,5	6	0,0055	22,5
LS 112 M	4	1438	26,8	8,3	0,57	0,76	0,83	83,4	84,2	84,2	7,1	2,5	3	5,7	6	0,0067	24,9
LS 132 S	5,5	1447	36,7	11,1	0,67	0,79	0,83	85,8	86,4	85,7	6,3	2,4	2,8	7,7	6	0,014	36,5
LS 132 M	7,5	1451	49,4	15,2	0,61	0,74	0,82	84,9	86,4	87	7	2,4	2,9	10,5	6	0,019	54,7
LS 132 M	9	1455	59,3	18,1	0,62	0,74	0,82	86,2	87,6	87,7	6,9	2,2	3,1	12,5	4	0,023	59,9
LS 160 MP	11	1454	72,2	21	0,67	0,79	0,86	87,4	88,6	88,4	7,7	2,3	3,2	14,5	1	0,030	70
LS 160 LR	15	1453	98	28,8	0,69	0,78	0,84	88,4	89,8	89,4	7,5	2,9	3,6	20	1	0,036	86
LS 180 MT	18,5	1456	121	35,2	0,67	0,79	0,84	90,3	90,8	90,3	7,6	2,7	3,2	24,4	1	0,085	100
LS 180 LR	22	1456	144	41,7	0,68	0,79	0,84	90,9	91,2	90,7	7,9	3	3,3	28,9	1	0,096	112
LS 200 LT	30	1460	196	56,3	0,69	0,8	0,84	91,5	92	91,5	6,6	2,9	2,9	39	2	0,151	165
LS 225 ST	37	1468	241	68,7	0,7	0,8	0,84	92,9	93,1	92,5	6,3	2,7	2,6	47,6	2	0,24	205
LS 225 MR	45	1468	293	83,3	0,7	0,8	0,84	93	93,3	92,8	6,3	2,7	2,6	57,7	2	0,29	235
LS 250 ME	55	1478	355	101	0,71	0,8	0,84	93,2	93,8	93,6	7	2,7	2,8	70	3	0,63	320
LS 280 SC	75	1478	485	137	0,71	0,8	0,84	93,8	94,4	94,2	7,2	2,8	2,9	94,8	3	0,83	380
LS 280 MD	90	1478	581	164	0,71	0,8	0,84	93,8	94,5	94,4	7,6	3	3	113,5	3	1,03	450
LS 315 SP	110	1484	708	197	0,74	0,82	0,85	93,9	94,7	94,8	7	2,7	2,7	136,5	3	2,32	670
LS 315 MP	132	1484	849	236	0,74	0,82	0,85	94,1	95	95	7,6	2,9	3	163,5	3	2,79	750
LS 315 MR	160	1484	1030	286	0,74	0,82	0,85	94,1	95	95	7,7	2,9	3	198,1	3	3,27	845
LS 315 MR ●	200	1486	1285	359	0,69	0,79	0,84	95,1	95,8	95,8	8,1	3,1	3,4	248,5	3	3,27	860

APPENDIX 2

Schneider Electric
Technical specifications n° 207
Electric motors

Available in full on **Celène**



Technical collection

Cahier technique no. 207

Electric motors

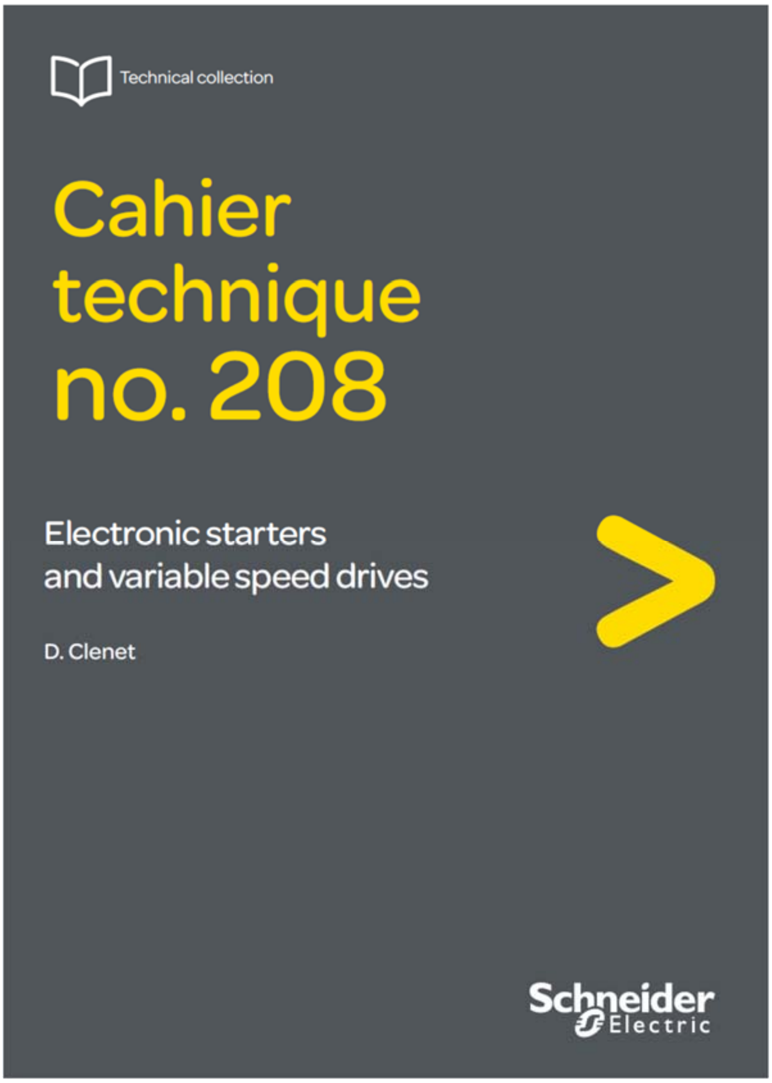
E. Gaucheron

Schneider Electric

APPENDIX 3

Schneider Electric
Technical specifications n° 208
Electronic starters and variable speed drives

Available in full on **Celène**



Technical collection

Cahier technique no. 208

Electronic starters and variable speed drives

D. Clenet

Schneider Electric

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Labwork

DC MACHINE

M1 AESM
Electrical Engineering

PW – DIRECT CURRENT MACHINE

The objective of the PW is to operate a direct current machine as a generator and then as a motor and to record, in each of the operations, the electrical and mechanical characteristics specific to the machine.

The direct current machine consists of two main parts : one fixed, the stator which acts as an electromagnet or "**inductor**", the other movable, the rotor which is the rotating armature of the electromagnet, the « **armature** ».

The **inductor** consists of windings wound around polar cores arranged on the periphery of the stator. Crossed by an « inductive » current or **excitation current, I_e**, it allows the production of a **magnetic flux,Φ** . On small machines, the inductor is replaced by permanent magnets.

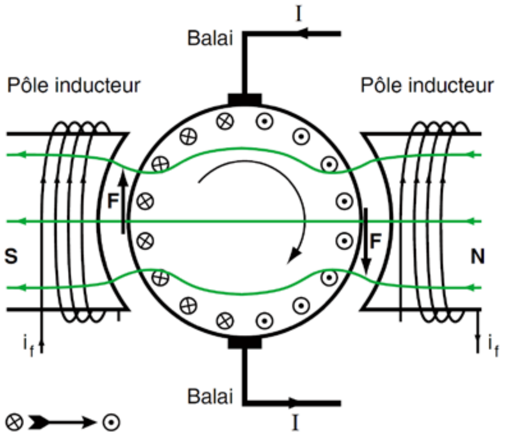
The **armature**, or rotor, is the continuity of the stator magnetic circuit. On the periphery, notches have been cut in which the electrical circuit conductors of the armature welded to two collector blades are housed.

The **collector** is a set of copper blades, insulated laterally from each other, and arranged in a cylinder at the end of the rotor.

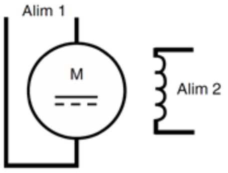
The **brushes**, carried by the stator, rub against the commutator blades. The commutator-brush assembly allows the direction of the current in the rotor conductors to be reversed as they cross the neutral line of the machine.

A direct current machine is reversible: it can operate as a **generator** as well as a **motor**.

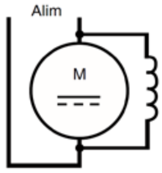
The inductor can be connected to the armature in various ways as shown in the figure opposite.



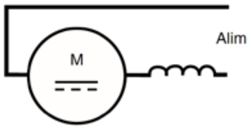
Machine à excitation séparée



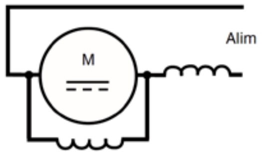
Machine à excitation shunt

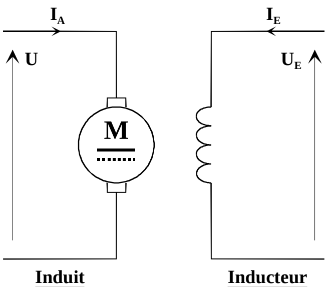


Machine à excitation série

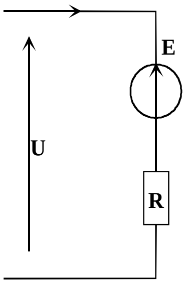


Machine à excitation composée





Symbol



Equivalent armature scheme

1) TEST AS A DIRECT CURRENT GENERATOR WITH INDEPENDENT EXCITATION

1.1) Wiring diagram

The DC machine studied operates first as a generator and is driven by an asynchronous motor powered by a frequency converter. **The power supply to the inductor is provided independently**.

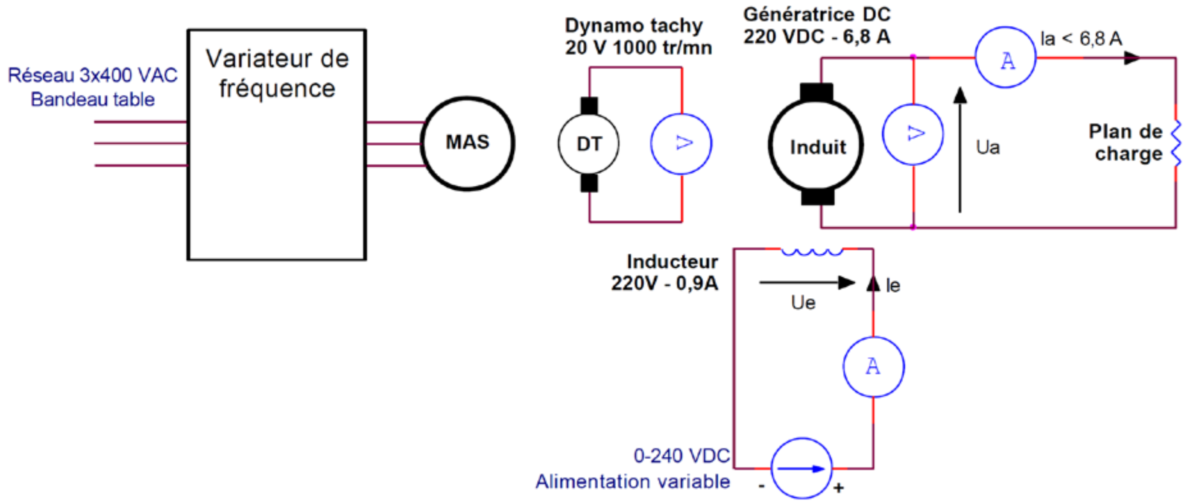
$$E_a = k.\phi.\Omega$$

E_a : electromotive force (e.m.f) or armature no-load voltage in Volt

k: machine characteristic constant,

Φ : Inductive flow in Weber,

Ω : rotor rotation speed in radians per second



- **Read** the characteristics plated on the machine.
- **Wire** the diagram above.

1.2) No-load test

The **asynchronous motor**, powered by a frequency converter, drives the **generator** at its rated speed. During a no-load test, the generator does not deliver any current (I_a = 0 A).

- At nominal speed, **read** using a spreadsheet and **plot**, in real time, the no-load characteristic of the generator $E_a = f(I_e)$ for I_e varying from 0 A to I_{en} and then from I_{en} to 0 A.
- **Comment** and **explain** the appearance of the plots.

1.3) Load test

The direct current generator, driven at its nominal speed under its excitation current I_{en}, flows on a variable R load plane. It is used to adjust the current I_a.

- At nominal speed, **read** using a spreadsheet and plot, in real time, the load characteristic **$U_a = f(I_a)$** for I_a varying from **0 to I_{an}**.
- From the characteristics $E_a = f(I_e)$ and $U_a = f(I_a)$, **plot**, on the same graph, the variation of the total armature voltage drop **$\Delta Ua = f(Ia)$.**
- **Comment** and **explain** the appearance of the plots.

1.4) Adjustment characteristic (optional, at the teacher's request)

When the speed « n » remains constant, while the load and the current output « I_a » vary, the excitation current « I_e » must be acted on the current to maintain U_a at a constant value. The characteristic $I_e = f(I_a)$ is then called the setting curve.

- While maintaining the speed at the nominal value and for I_a varying from 0 to I_{an}, **set** I_e to maintain $U_a = 0.5 \, . \, U_{an}$, without exceeding 1.25 I_{en}. **Read** with a spreadsheet and **plot**, in real time, the adjustment characteristic $I_e = f(I_a)$.
- **Comment** and **explain** the appearance of the layout and the value of this feature.

1.5) Measurement of armature resistance (optional, at the teacher's request)

The armature resistance R_a is measured using the voltamperometric method. The machine is stopped and not excited. The armature is powered by a variable power supply capable of delivering the I_{an} current.

- For three values of Ia ($I_{an}/2$, $3.I_{an}/4$, I_{an}), **read** the voltage at the armature terminals by rotating the rotor during the measurement. **Deduce** the value of R_a.

1.6) Energy balance

A direct current generator is a machine that receives energy in two forms:

- on its shaft, it receives mechanical energy from the drive motor (electric, diesel, turbine);
- in the inductor, it receives electrical energy from a DC voltage source.

It restores this energy in two forms:

- the useful energy, which it supplies to a load in electrical form;
- the energy lost, for different reasons, but which is always transformed into heat.

- **Give** an expression of the useful power of the generator.
- **Give** the origin of the power absorbed by the generator and **give** it an expression.
- **Provide** an expression of the generator's performance.

2) TEST AS A DIRECT CURRENT MOTOR WITH INDEPENDENT EXCITATION

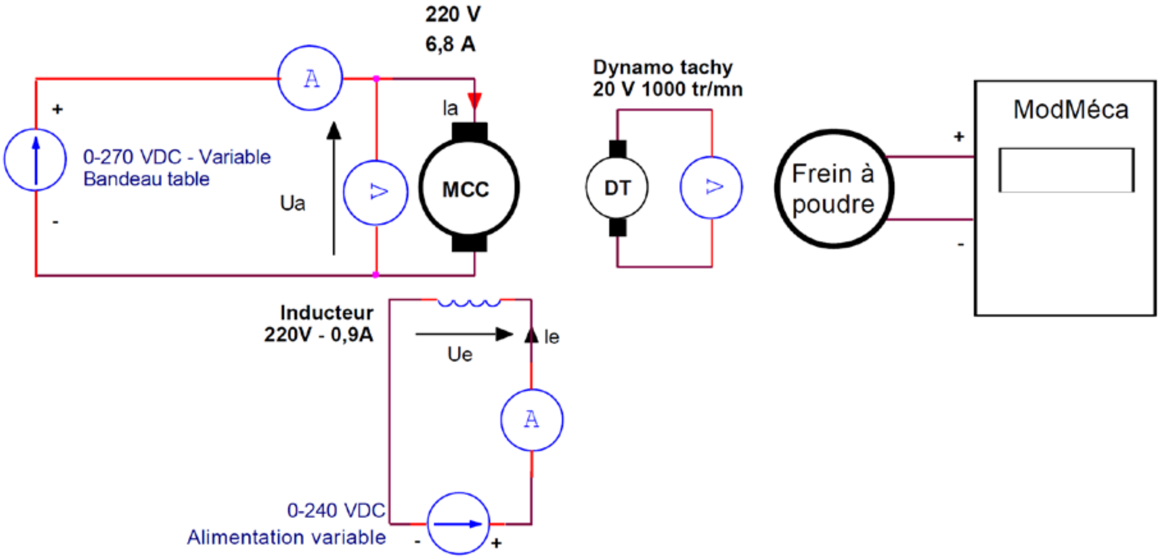
2.1) Background

The torque characteristic as a function of speed is the mechanical characteristic that must be available to choose a motor regardless of its technology.

To draw it, the following test uses the **power balance method**. The useful torque of the machine is obtained indirectly from the calculation of the useful power.

2.2) Wiring diagram

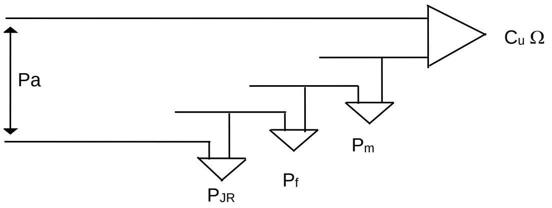
The machine studied in the first part becomes the driving force. The mechanical load is the powder brake controlled by the mechanical display module.



A DC motor will run wild if its armature is powered at rated voltage while the excitation is off*.* *Under these conditions, it is advisable to continuously monitor the power supply to the DC Motor inductor.*

2.3) Power balance

The power shaft opposite shows the engine power balance.



- P_a : electrical power absorbed by the motor armature.
- P_{JR} : power dissipated by the Joule effect through the motor armature.
- P_f : ferromagnetic losses of the motor essentially located at the rotor.
- P_m : mechanical losses due to friction in the bearings, on the collector and in the air.
- P_e : electrical power absorbed by the motor inductor.

Knowledge of the value of losses is necessary. These values are given in **the appendices**.

- **Give** the expression of the useful torque, C_u, as a function of the power absorbed by the machine, P_a, the losses of the machine, P_{JR}, P_f and P_m, and the speed of the machine, n.

$$\mathbf{C_u, = f(P_a, P_{JR}, P_f, P_m, n)}$$

- **Adapt** the previous relationship by introducing U_a, I_a and R_a instead of P_a and P_{JR}.

2.4) Procedure for starting the engine

- **Read** again the characteristics plated on the machine.
- **Wire** the above diagram.
- **Set** the armature voltage to zero.
- **Supply** power to the « Inducer » circuit and **set** the excitation current I_e to its nominal value I_{en}.
- **Start** the motor gradually, increasing the voltage across the armature to U_{an}. **Set** the excitation current I_e to return to the nominal speed, n_{nom}.
- Through six successive measuring points, gradually **charge** the motor with the powder brake to increase the current I_a to its nominal value, I_{an}. If necessary, **readjust** U_{an}; the supply voltage must remain constant throughout the test.

2.5) Reading of the mechanical characteristic Cu = f(n)

- At each measurement point, **read**, using a spreadsheet, U_e, I_e, U_a, I_a, and n and **plot**, in real time:
  - the mechanical characteristic, $\mathbf{C_u = f(n)}$, for I**a** varying from **0 to $\mathbf{I_{an}}$**.
  - the efficiency characteristic, $\boldsymbol{\eta} \mathbf{= f(P_u)}$, of the motor,
  - the current characteristic as a function of torque, $\mathbf{I_a = f(C_u)}$, of the motor.
- **Comment** and **explain** the appearance of the plots.

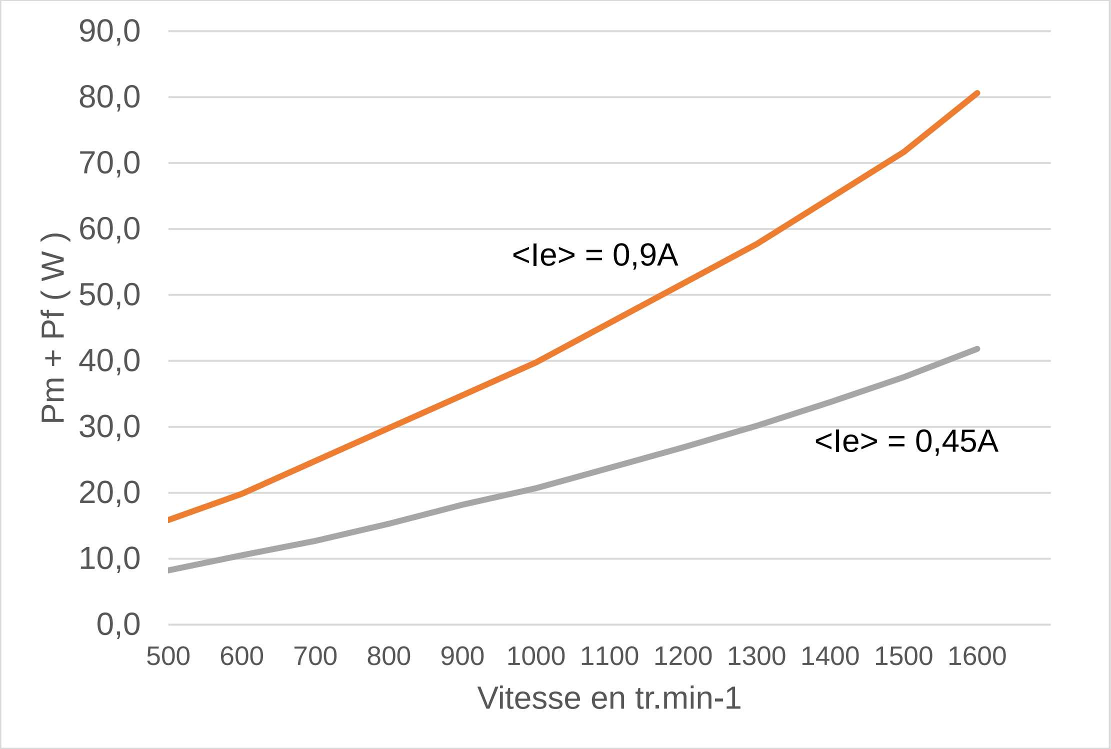
- **Repeat** the operation with a voltage U_a set to $3.U_{an}/4$. On the same graph, **plot**, in real time, the same characteristics for I_a varying from **0 to $\mathbf{I_{an}}$**. **Comment** and **explain** the appearance of the new plots.

APPENDICES

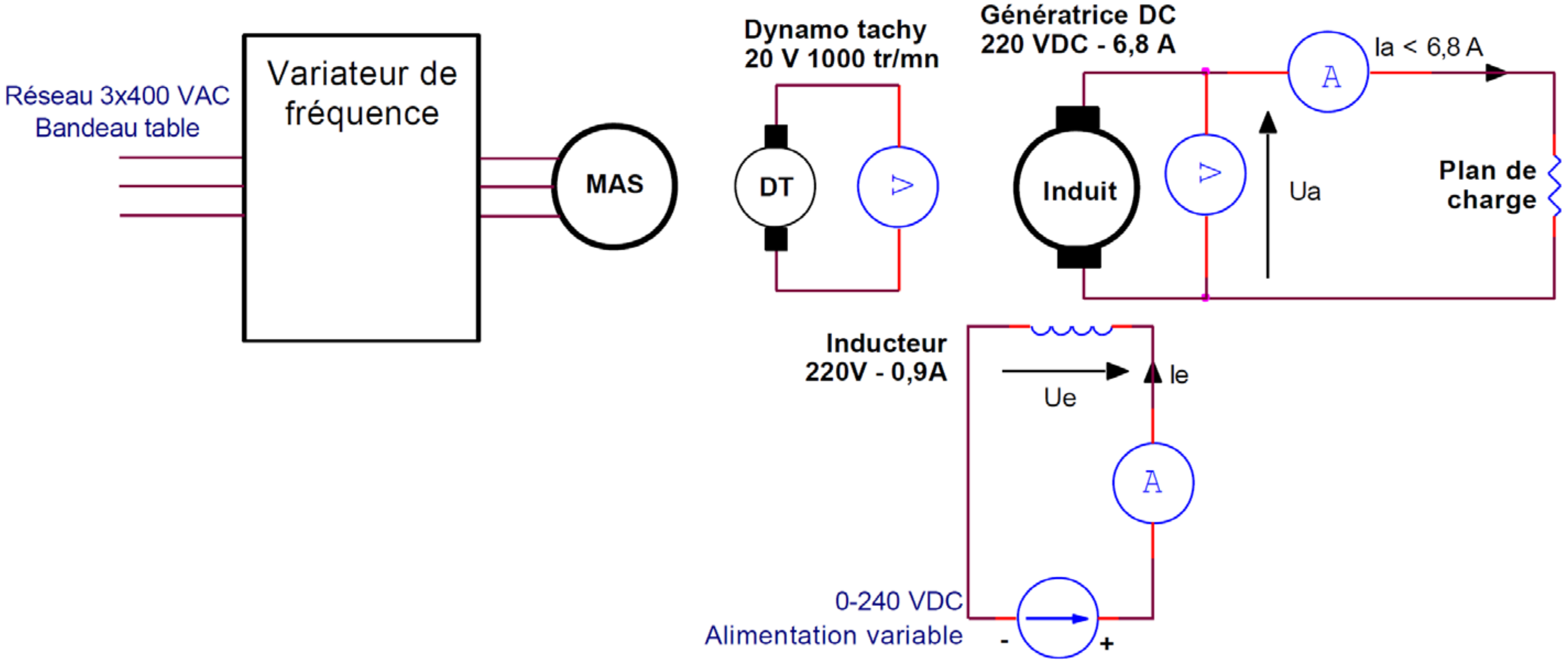
Reading of ($P_m + P_f$) (Ω , I_e)

- $R_a = 4,2\ \Omega$

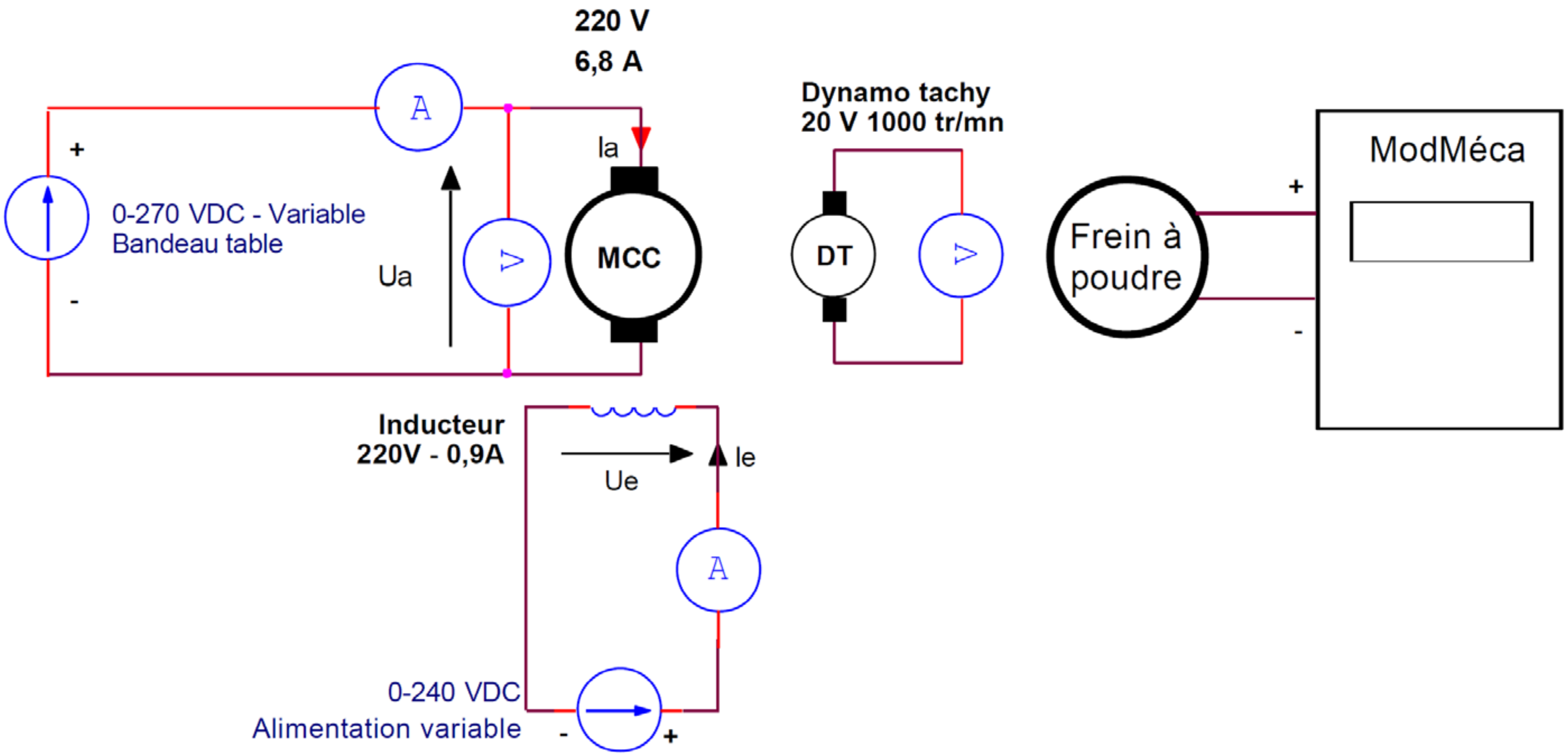
	$\langle I_e \rangle = 0,9$ A			$\langle I_e \rangle = 0,45$ A		
n (tr/min)	P_a (W)	I_a (A)	$P_m + P_f$ (W)	P_a (W)	I_a (A)	$P_m + P_f$ (W)
500	16	0,175	15,9	8,3	0,123	8,2
600	20	0,185	19,9	10,6	0,13	10,5
700	25	0,195	24,8	12,8	0,136	12,7
800	30	0,205	29,8	15,4	0,145	15,3
900	35	0,22	34,8	18,3	0,153	18,2
1000	40	0,23	39,8	20,8	0,158	20,7
1100	46	0,24	45,8	23,9	0,166	23,8
1200	52	0,25	51,7	27,0	0,172	26,9
1300	58	0,26	57,7	30,3	0,179	30,2
1400	65	0,27	64,7	33,9	0,188	33,8
1500	72	0,28	71,7	37,7	0,197	37,5
1600	81	0,3	80,6	42,0	0,202	41,8



Test as a DC generator with independent excitation Wiring diagram



Test as a DC motor with independent excitation Wiring diagram



POLYTECH ORLÉANS
École d'Ingénieurs de l'Université d'Orléans

Labwork

STARTER ALTERNATOR

M1 AESM
Electrical Engineering

PW VALEO STARTER ALTERNATOR

The starter-alternator is a device that addresses the notion of hybridization of the thermally propelled motor vehicle in its softest form.

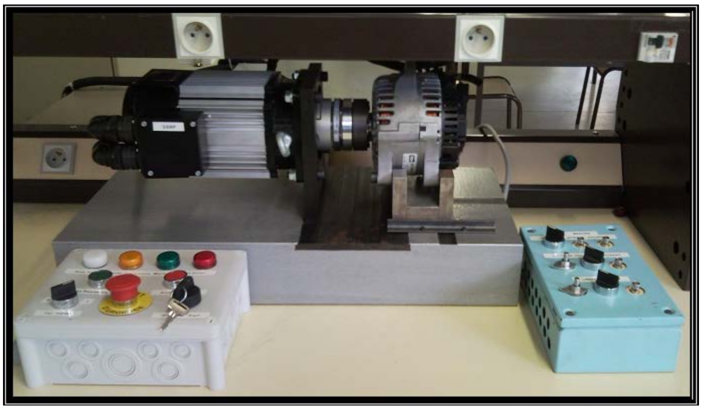
In the race to reduce fuel consumption and therefore reduce GHGs (Greenhouse Gases), its contribution lies in the "Stop **and Start"** function. This consists of shutting off the operation of the combustion engine (Powertrain, GMP) duringphases of stopping at traffic lights, stops in traffic jams, or stops for any other reason. The expected reduction in consumption is of the order of 2 to 10%.

To achieve this, **the Valeo starter-alternator,** which is a polyphase synchronous machine with a wound inductor, performs the following functions:

- FP1: Start the GMP vigorously at higher rates than the oldDCstarter,
- FP2: recharge the battery in the rolling phases thus replacing the alternator which it retains the shape and nature of synchronous alternating current machine.

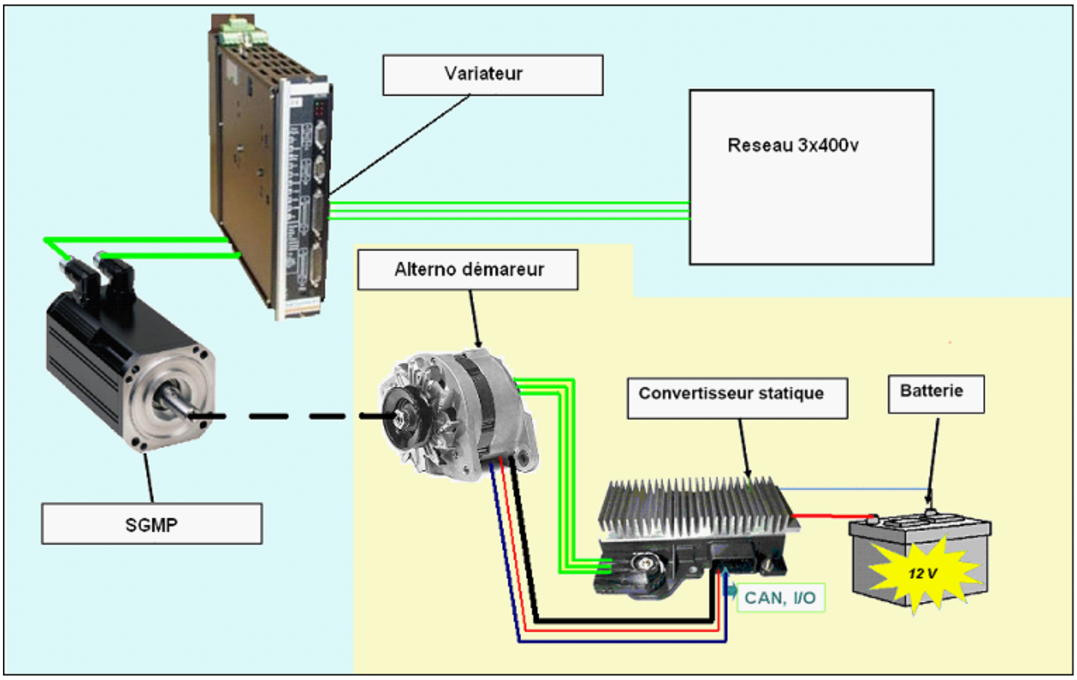
The ECU (Engine Control Unit),the power electronics associated with it, present on the system in the form of a finned case, ensuring the heat dissipation of the losses inherent in the switching of semiconductors, contributes to the functions:

- FP1, by raising the three-phase voltages from thebattery s(14VDC) using a DC/AC converter (inverter) and a full-flow chopper on the inductor so as to achieve a high torque (40 to 60 N.m) for short periods corresponding to the GMP start-up time.
- FP2, using the previous structure in the form of an AC/DC converter (pulse width modulation controlled rectifier) associated with the same chopper adjusting the current in the inductor. This makes it possible to adjust the battery charge under the disturbance of DSD Voltages produced proportional to the speed of rotation.



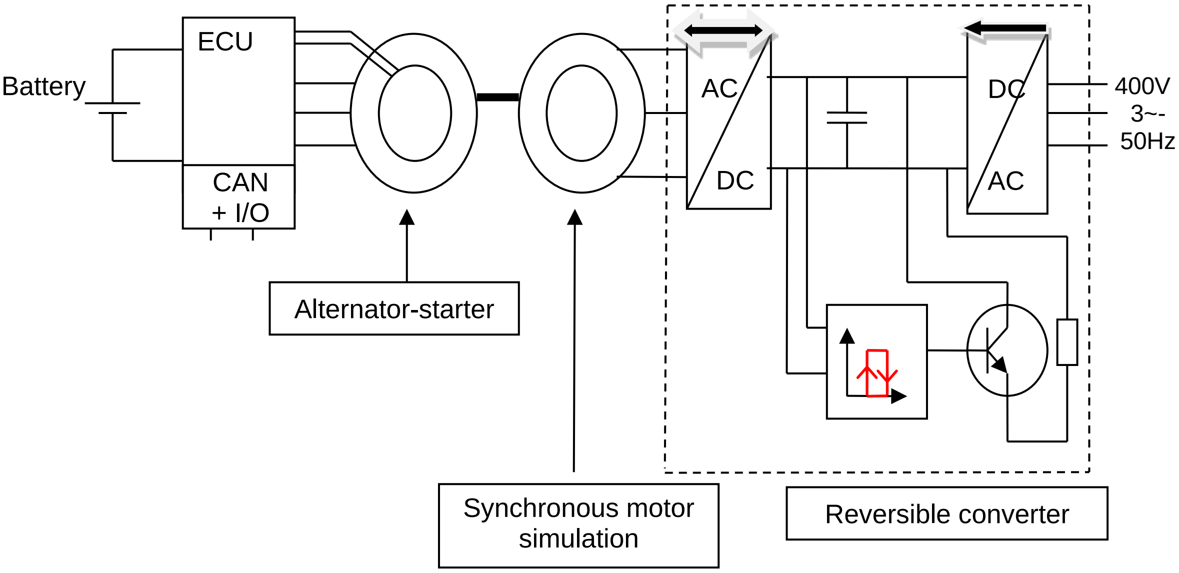
The objective of the TP is to illustrate both functions using a test bench on which the Powertrain is simulated by a synchronous machine rated SGMP in a complete vehicle cycle START-RUN-BRAKING.

The test bench



On the bench, there is:

- The **14VDC battery,**
- **ECU** (Engine Control Unit),
- **the alternator-starter AD,**
- the **SGMP Powertrain** simulated by a brushless servo motor and its converter.



Bench synoptic

PART ONE: WRITTEN PREPARATION

Start-RUN-BRAKE operating cycle

A complete **start-drive-brake** cycle consists of the 7 phases detailed below:

Phase 1: The starter-alternator (SA) works in synchronous motor and drives the combustion engine. The SGMP, receiver of mechanical energy, works as an electric generator to its network.

Phase 2: The combustion engine starts following the initiation of combustion. The SGMP becomes the driving force. The starter-alternator also works as an engine. Driven by two motors, the axis accelerates.

Phase 3: The speed has increased but is still insufficient for the starter-alternator to produce electricity. The SGMP is alone and the alternator only presents its losses.

Phase 4: Still driven by the SGMP at a speed sufficient to produce electrical energy, the starter-alternator then operates as an alternating electric generator (alternator). At the end of this phase, the start-up of the combustion engine is complete.

Phase 5: The vehicle is driving at a constant speed. The SGMP is the driving force. The starter-alternator works as an alternator and helps to charge the accumulator battery via the ECU.

Phase 6: The vehicle decelerates but in a sufficient speed range for the ECU to keep charging the battery.

Phase 7: The vehicle has decelerated until stationary but in a range of speed for which the production of electricity by the ECU is no longer possible. The starter-alternator is free-wheeling. Only friction remains.

1) In a table, for each phase of the cycle, **indicate:**

- the operation of each of the two machines, engine or receiver for the SGMP, motor or generator for the SA,
- the operating phase of the battery, (charging or discharging),
- the operating phase of the static converter (inverter or rectifier),
- the sign of the acceleration of the tree (++, +, 0, - or - -),
- the sign of the power received by the shaft of the SA ($P_{meca} > 0$ if the SA receives energy).

Driveline

2) Using Appendix 2, **calculate** the driveline reduction ratio.

The synchronous machine, the starter-alternator

3) From the course, **recall,**in a few lines, the principle of the synchronous machine. **Indicate** what the electromotive force depends on.

The charging current of the battery must not exceed 150 A permanently to preserve the life announced by the manufacturer. It is assumed, for this part, that the vacuum voltage of the battery is 12.7 V and that its internal resistance is 10 mΩ.

4) **Calculate** the rated power to be provided by the synchronous machine in alternator mode.

The battery

5) **Identify** the characteristics of the test bench battery. **Calculate W**, the energy stored by the battery in Joule.

PART TWO: PRACTICAL ACTIVITIES

Implementation of the bench

6) Identify the different elements of the bench:
- The battery,
- The ECU,
- The SA,
- The synchone machine simulating the SGMP,
- The drive driving the SGMP machine.

7) Implement the bench by performing the procedure described in Annex 1

Default cycle

8) **Start** a default cycle by drawing using the "F1.2 - Measurements" panel.

9) **Find** on the track the seven phases of the complete cycle of the car START-RUN-BRAKING and **compare** to the forecasts of the preparation.

10) **Measure** on the plot:
- **C_{DEM}**,the torque of the alternator-starter necessary for the initiation of combustion,
- **n_C**, the speed of the GMP engine for which combustion starts remembering that in the actual engine the starter turns 2.6 faster than the Powertrain,
- **C_R**, the torque of the engine in the running phase,
- **n_R**, the speed in the rolling phase,
- **n_{FR}**, the speed at which the alternator-starter ceases to produce electrical energy.

11) In phase 4, the SGMP being driven in torque, the alternator-starter becomes alternator. **Justify** the singular situation appearing on speed.

Charging and discharging the battery

12) **Draw** a diagram to record and visualize, using an oscilloscope, the current exchanged between the battery and the ECU and the battery voltage during a default cycle (panel F2.1). **Have** the diagram validated by the teacher.

13) **Wire** the validated diagram **OFF. Have** the wiring validated by the teacher.

14) **Perform** enough default cycles to measure:
- the duration of the start, **T_D**,
- the current **I_D** consumed during this phase (in this phase, the current is not constant, estimate its average value),
- the voltage drop at the terminals of the battery □**U_D**,
- the value of the driving time, **T_R**,
- the value of the current during the alternator phase, **I_R**,
- the value of the increase in voltage at the terminals of the battery during driving, □**U_R**.

15) **From this deduce** the value of the internal resistance **R_{BAT}** of the battery and **I_{DC}**,the presumed short circuit current of the battery.

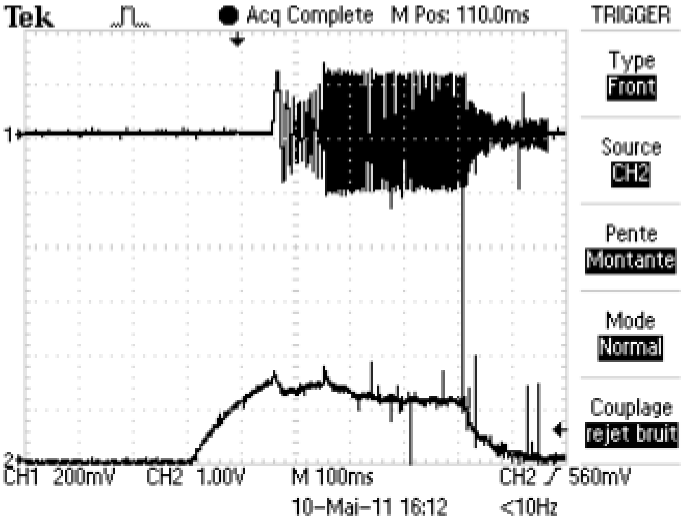
16) Considering the currents as constants on the oscillograms, **calculate**, in Coulombs and Ah, the amount of electricity consumed at start-up **Q_D** and the amount of electricity recovered duringrunning **Q_R**, then □**Q**,the contribution to thecharging ordischarging of the battery of a default cycle of the dynamometer.

17) The battery undergoes a self-discharge of 5% every month; **calculate** the number of default cycles needed to compensate for this self-discharge after 6 months of inactivity.

18) There are 60 TP sessions; **calculate** the number of default cycles required per session to ensure charging under the previous conditions.

Unit test of the starter-alternator: panel F2.1

The following oscillograms show, on **track 1,**the current in the **stator (armature)** and, on channel 2, the current in the rotor **(inductor)** of the alternator-starter during the unit test (panel F2.1) with two different time bases. In this test, the alternator-starter operates as a starter (engine) and unladen.



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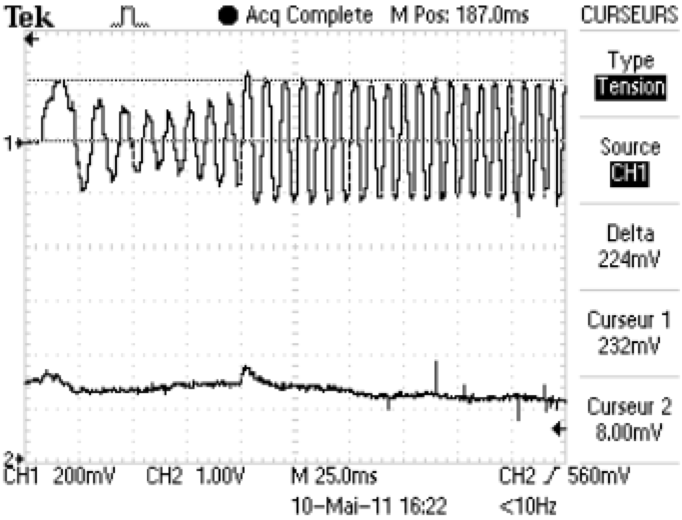

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19) Comment on the pace of the two currents from the point of view:

- the appearance and disappearance of the inductor flow
- the frequency and amplitude of currents in the stator phases.

Parameterized cycle:

20) Propose a rolling time value that would allow to recharge the battery that would have suffered an inactivity of 1 month or that would compensate for the series of untimely starts made voluntarily.

21) Measure battery voltage. **Set** the proposed duration and then start the parameterized test. **Measure** the battery voltage after the test to see the effect. **Conclude** on the evolution of the battery voltage.

APPENDIX 1: VALEO STARS STARTER-ALTERNATOR

VALEO press kit
Frankfurt Motor Show 2007

The StARS alternator-starter, a Valeo exclusive, gives manufacturers the opportunity to reduce consumption in urban driving by up to 15% without having to disrupt their engine architecture.

Rewarding technology

Reducing consumption, greenhouse gases and polluting emissions is one of the major challenges facing the automotive industry today. Manufacturers are investing heavily in research and development to further improve the thermal efficiency of engines, but advances are being made in small steps. When we see that in urban driving a car is nearly 35% of its time stationary and that its engine runs unnecessarily at idle, the use of the Start-Stop function becomes obvious: it allows the engine to stop momentarily, for example the time of a red light, and its restart as soon as a power is requested. The StARS alternator-starter (Starter Alternator Reversible System) performs this function completely automatically and provides a very significant reduction in consumption of up to 28% in a busy urban cycle.

The StARS alternator-starter combines alternator and starter functions. In starter mode, the start is immediate and silent thanks to its permanent connection by belt to the crankshaft. The alternator mode benefits from a new technology that improves electrical efficiency. These two major advantages position the StARS alternator-starter as the ideal product bringing real gains in terms of consumption, but also comfort by eliminating vibrations and noise emitted by the engine, in the shutdown and restart phase.

Due to its advanced operating mode, the StARS alternator-starter adapts to all engine shutdown and restart strategies desired by manufacturers. The system can take into account a large number of parameters related to the engine, clutch, gearbox, braking system or other comfort and safety equipment. It also allows the engine to be restarted during shutdown if the driver unexpectedly changes his mind, an advantage that is not achievable with a conventional starter. StARS can be combined with all petrol engines up to 2.0 litres and all diesel engines up to 1.6 litres, as well as with all types of gearboxes. From 2009, it will be able to equip any petrol and diesel vehicle regardless of engine displacement.

Valeo was the first equipment manufacturer to bring an alternator-starter to the market in 2004. StARS was launched on the Citroën C3 1.4i 16V, then on the Citroën C2. The smart fortwo mhd (micro hybrid drive) now benefits from the advantages of the StARS alternator-starter. It thus offers a 13% reduction in consumption in loaded urban driving, i.e. a consumption value reduced to 4 l/100 km and a CO2 level of only 103 grams/kilometre (provisional data). The ingenuity of the StARS start-up alterno-starter has enabled Valeo to win the 2006 PACE Award, the EPCOS/SIA Grand Jury Prize and the 2004 Engineers of the Year Award, distinctions that confirm the interest of the automotive industry in this device.

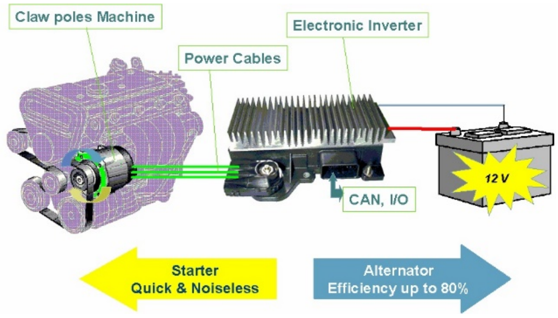
The principle of operation

The drive of the alternator-starter is carried out by a belt that can also be used for other accessories such as the air conditioning compressor, the water pump or power steering. A reversible tensioner allows it to accept power transmission in one direction or the other, depending on whether the StARS alternator-starter works as a starter or a generator. It is paired with a battery using technology that accepts a greater number of charge/discharge cycles. It is also equipped with a sensor that allows the system to inhibit the Start-Stop function in case of too low a load or to control the restart of the engine if the load level falls below a critical threshold.

The StARS alternator-starter in detail

The StARS alternator-starter is a synchronous machine with claw rotor. This machine is cooled by air circulation and operates in three-phase current, the continuous conversion under 12 volts being carried out by a remote electronic converter.

In starter mode, the electronic converter provides three currents out of phase of 120 ° in relation to the information of the 3 position sensors of the machine. It is capable of delivering a current of 600 amps generating high torque for immediate combustion engine drive and at higher rpm than with a conventional starter. The machine thus starts the engine in less than 0.4 s. It then connects immediately in alternator mode. In this configuration, the rectification of the 3 phases carried out by the electronic converter uses the technology of the MOSFET Field Effect Transistor. This is one of the reasons for the very good efficiency of the StARS alternator-starter since it reaches a value of 82%, 10 points better than the most efficient conventional alternator on the market. The machine flows a current of up to 180 amps.



The advantages of the StARS alternator-starter

The advantages for the manufacturer

- The StARS alternator-starter offers a significant reduction in consumption and CO2 emissions for a minimal investment.
- The starting power is high: 2.5 kW at 14 Volts.
- The electrical efficiency is higher than that of a conventional alternator.
- A restart of the engine during shutdown is possible, for example if the driver changes his mind unexpectedly.
- Installation on the engine block and electrical integration are simple.
- The length of the powertrain is not increased, unlike the case of an alternator-starter incorporated into the shaft line.

The benefits for the user

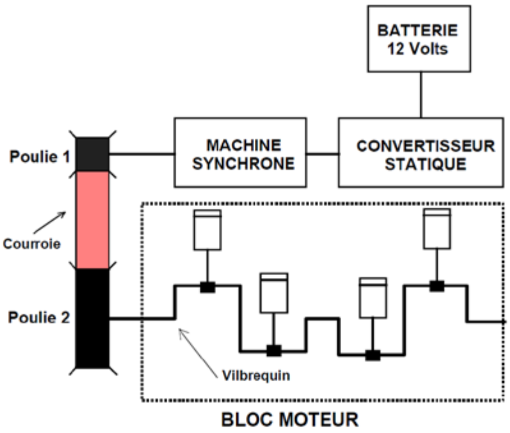
- Consumption is reduced by up to 15% in the urban cycle.
- CO2 emissions are reduced by up to 15% in the urban cycle.
- Shutting off and restarting the engine is automatic.
- The restart of the engine is immediate (in less than 350 msec) and completely silent.
- Engine noise and vibration are eliminated during momentary shutdown, i.e. for almost 35% of the time in urban driving.

Video "Start Stop Citroën C3": https://youtu.be/dFNg4jUjhXc
Video "Valeo presents micro-hybrid Stop Start i-StARS": https://youtu.be/VJSEQaxAh4c

APPENDIX 2: TECHNICAL CHARACTERISTICS

Driveline

- d_1 = 60 mm: diameter of pulley 1;
- d_2 = 160 mm: diameter of pulley 2;
- C_{RV}: resistant torque on the crankshaft side. This torque is equal to the take-off torque C_{DV} plus a compression torque C_{PV} which depends on the speed but which can be considered constant and equal to 40 Nm for the car mentioned above;
- C_{DV}: take-off torque on the crankshaft side. This torque is worth 80 Nm cold (- 25 ° C) and 40 Nm hot for a gasoline car with a displacement of 1400 cm^3. This torque is constant during the start-up time of the combustion engine; J_{VV} = 150 g.m²: moment of inertia of the masses in motion on the crankshaft side with respect to the axis of rotation of it;
- J_{RM} = 4 g.m²: moment of inertia of the rotor of the synchronous machine with respect to its axis of rotation;
- Ω_V: rotational speed in rad/s of the crankshaft;
- Ω : speed of rotation in rad/s of the shaft of the synchronous machine.



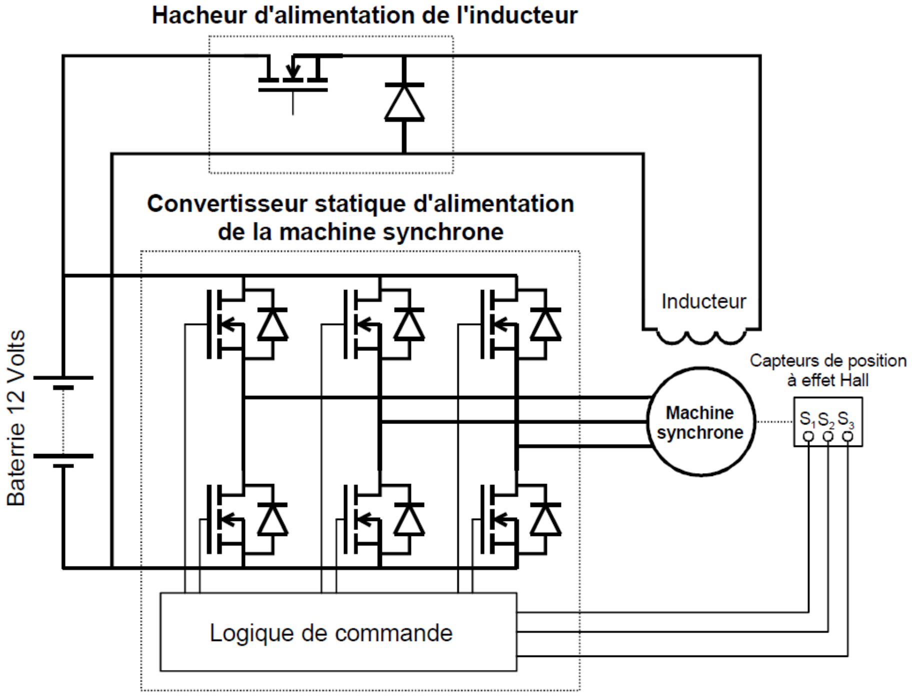
Electrical conversion chain

Synchronous machine

It is a three-phase synchronous machine with a coiled rotor. The statoric windings are coupled in a star.

- p = 6: number of pole pairs of the machine;
- N_{ES} = 36: number of notches at the stator, there is one notch per pole and per phase;
- Each statoric winding consists of 4 parallel conductors of 1.18 mm in diameter each;
- e = 0.35 mm: thickness of the gap;
- D_R = 105 mm: rotor diameter;
- D_M = 150 mm: diameter of the machine;
- L_M = 160 mm: length of the machine;
- N_{ER}: number of notches at the rotor. There is one notch per pole;
- N_{CR} = 180: number of conductors per notch at the rotor;
- I_{EXN} = 20A: nominal excitation current at the rotor;
- the induction produced in the gap by a rotor magnetic pole and for the nominal excitation current is about 1 Tesla;
- R_{EX} = 0.5Ω: resistance of the inductor;
- L_{EX} = 0.1H: inductor inductor;
- Rated power of the machine: 2.5 kW under 14 V in steady state for alternator operation with 100°C room temperature and a rotational speed of 6,000 rpm.

Static converter powering the synchronous machine



Electrical power diagram

Each switch consists of a MOS transistor with an anti-parallel diode.

In starter mode, the converter operates as a full-wave inverter. The transistors are controlled via the three Hall effect sensors placed at the end of the shaft of the machine.

In generator mode, the battery is recharged. Transistors are no longer controlled. Only the diodes conduct and ensure the straightening of the voltages, res up in the synchronous machine.

The static converter consists of three SK300MB075 reference modules.

Inductor power series chopper

It consists of a MOS transistor and a diode. The hash frequency is 250 kHz.

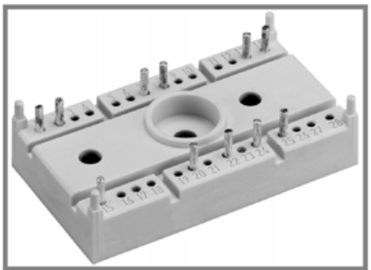
In starter mode the duty cycle of the chopper is 1, the transistor is constantly driving, and the excitation current is equal to its maximum value.

In generator mode the chopper allows the adjustment of the excitation current in order to control the charging current of the battery.

12 Volt battery

This is a standard 12 V, 5 0Ah lead-acidbattery.

SK 300MB075



SEMITOP® 3

Mosfet Module

SK 300MB075

Preliminary Data

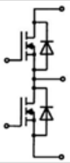
Features

- Compact design
- One screw mounting
- Heat transfer and isolation through direct copper bonded aluminium oxide ceramic (DCB)
- Trench technology
- Short internal connections and low inductance case

Typical Applications

- Low switched mode power supplies
- DC servo drives
- UPS

[1] Maximum PCB temperature, at pins/PCB contact, = 85°C



MB

Absolute Maximum Ratings		T_s = 25 °C, unless otherwise specified	
Symbol	**Conditions**	**Values**	**Units**
MOSFET			
V_{DSS}		75	V
V_{GSS}		±20	V
I_D	T_s = 25 (80) °C; [1]	290 (210)	A
I_{DM}	t_p < 1 ms; T_s = 25 (80) °C; [1]	580 (420)	A
T_j		-40...+150	°C
Inverse diode			
$I_F = - I_D$	T_s = 25 (80) °C;	290 (210)	A
$I_{FM} = - I_{DM}$	t_p < 1 ms; T_s = 25 (80) °C;	580 (210)	A
T_j		-40...+150	°C
Freewheeling CAL diode			
$I_F = - I_D$	T_s = °C		A
T_j			°C
T_{stg}		- 40 ... + 125	°C
T_{sol}	Terminals, 10 s	260	°C
V_{isol}	a. c. 50 Hz; r.m.s.; 1 min (1s)	2500 / 3000	V

Characteristics			T_s = 25 °C, unless otherwise specified		
Symbol	**Conditions**	**min.**	**typ.**	**max.**	**Units**
MOSFET					
$V_{(BR)DSS}$	V_{GS} = 0 V, I_D = 5,6 mA	≥ V_{DSS}			V
$V_{GS(th)}$	$V_{GS} = V_{DS}$; I_D = 5,6 mA	2,5	3,3		V
I_{DSS}	V_{GS} = 0 V; $V_{DS} = V_{DSS}$; T_j = 25 (125) °C			100 (500)	µA
I_{GSS}	V_{GS} = 20V ;V_{DS} = 0 V			100	nA
$R_{DS(on)}$	I_D = 200 A; V_{GS} = 10 V; T_j = 25 °C			1,6	mΩ
$R_{DS(on)}$	I_D = 200 A; V_{GS} = 10 V; T_j = 125 °C		2,3	3	mΩ
C_{CHC}	per MOSFET				pF
C_{iss}	under following conditions:		18,9		nF
C_{oss}	V_{GS} = 0 V; V_{DS} = 25 V; f = 1 MHz		3,6		nF
C_{rss}			1,1		nF
L_{DS}			2,2		nH
$t_{d(on)}$	under following conditions:		350		ns
t_r	V_{DD} = 40 V; V_{GS} = 10 V; I_D = 300 A		620		ns
$t_{d(off)}$	R_G = 25 Ω		1250		ns
t_f			400		ns
$R_{th(j-s)}$	per MOSFET (per module)			0,45	K/W
Inverse diode					
V_{SD}	I_F = 300 A; V_{GS} = 0 V; T_j = 25 °C		0,8		V
I_{RRM}	under following conditions:				A
Q_{rr}	I_F = A; T_{vj} = °C; R_G = Ω				µC
t_{rr}	V_R = A; di/dt = A/µs				ns
Free-wheeling diode					
V_F	I_F = A; V_{GS} = V				V
I_{RRM}	under following conditions:				A
Q_{rr}	I_F = A; T_{vj} = °C				µC
t_{rr}	V_r = A; di/dt = A/µs				ns
Mechanical data					
M1	mounting torque			2,5	Nm
w			30		g
Case	SEMITOP® 3		T 24		

APPENDIX 3 : IMPLEMENTATION OF THE TESTBENCH

An icon of theapplication, **gemma.exe**, is present on
the desktop of the computer.

1) On and off modes

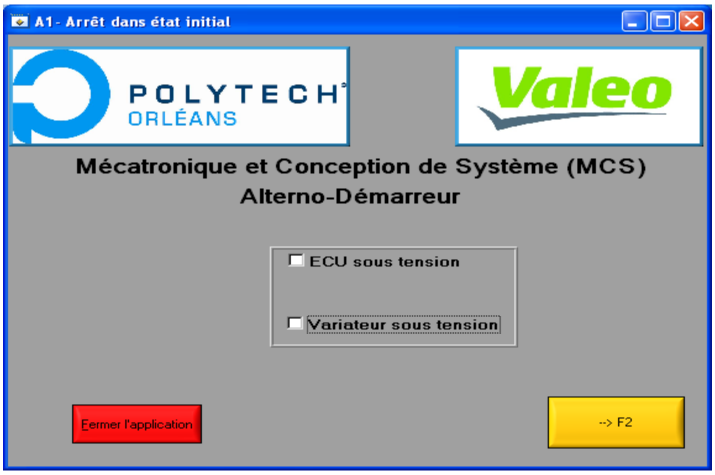
The proposed equipment makes it possible to carry outux cycles of operation:

- A default cycle with a driving time of 17 seconds,
- An adjustable rolling cycle beyond 17 seconds.

Gemma, given in Annex 4, specifies the start-up and shutdown modes on which the application is built. For this TP, the following browseue is A1, F1, F2 and A2.

The A1 stain is acquired from the launch of the application and requires the powering on of both electrical parts **ECU** and **SGMP** drive.

- ➢ After both converters have been poweredon, **check** the tabs,"ECU powered on" and "Dimmer on".
- ➢ Continue to "F2"



A1 - Arrêt dans état initial

Mécatronique et Conception de Système (MCS)
Alterno-Démarreur

☐ ECU sous tension

☐ Variateur sous tension

The computer application then follows the EMMA given in the appendix.

2) Preparation steps

"F2" gives access to the 3 unit tests that are mandatory to have access to the 2 cycles.

The unit tests make it possible to become familiar with the 2 engines:

- AD unit test
- VDS setup
- SGMP unit test

- ➢ **Select** each of the tests successively and **return** to this window

F2- Marche de préparation

2.1) Unit test of the starter-alternator: panel F2.1

This panel makes it possible to start the Valeo **start cycle of the alternator-starter** via the ECU by a vacuum **ON/OFF** step.
The number of trials automatically increases.

- **Click** "Start" to start a trial.
- **Click** "Back" to return to the F2 panel.

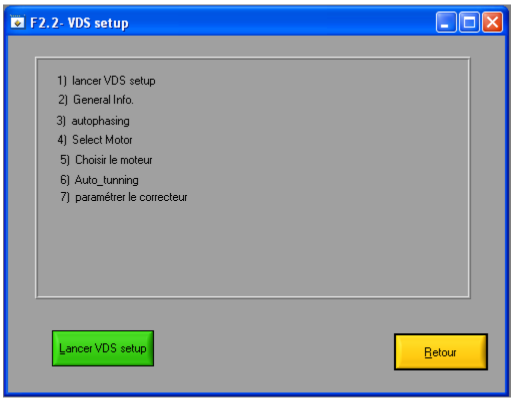
Nb d'essais: 0

2.2) Unit test of the infranor drive with its synchronous motor.

The VDS Setup activity makes it possible to carry out autophasing, setting the position sensor of the SGMP synchronous machine, and autotuning, self-setting the speed loop of the SGMP synchronous machine.

- **Validate** the VDS Setup of the F2 panel without opening the infranor application.
- **Click** "Back" to return to the F2 panel.

This procedure allows access to the SGMP unit test of the F2 panel.



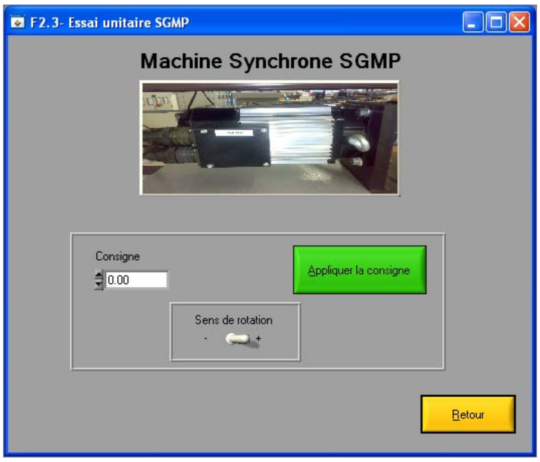
1) lancer VDS setup
2) General Info.
3) autophasing
4) Select Motor
5) Choisir le moteur
6) Auto_tunning
7) paramétrer le correcteur

2.3) SGMP unit test

The SGMP unit test hasaccess to 2 panels which are superimposed on the screen: F1.2 and F2.3.

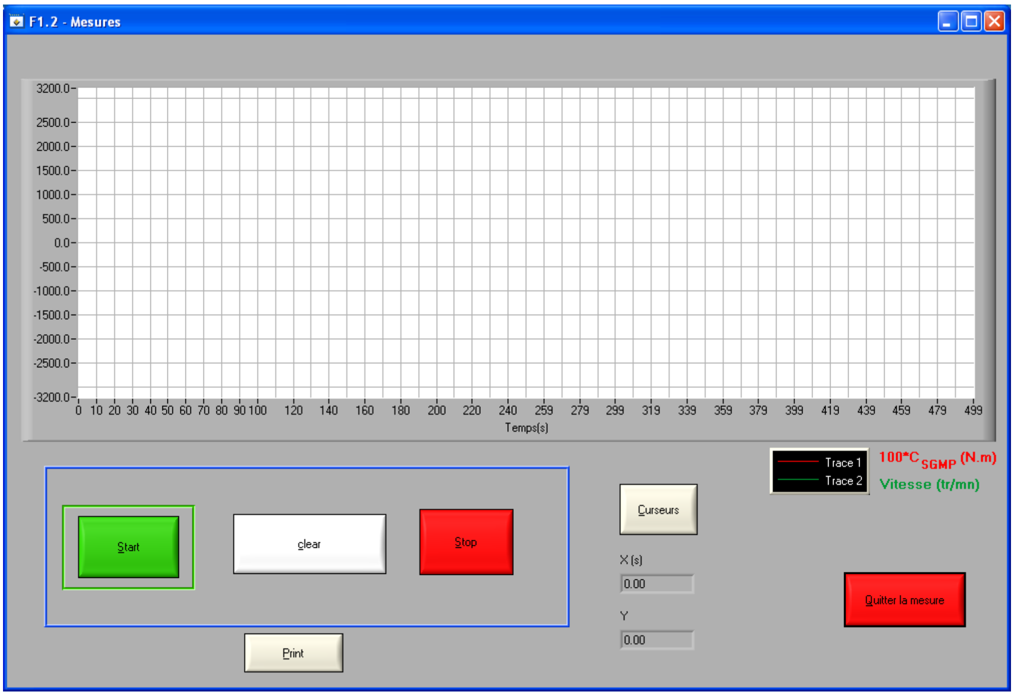
F2.3 isthe button box of the command:

- **Load** a speed set between 0 and 3000rpm (1000 for example).
- "Apply the instruction".
- The positive direction of rotation corresponds to that of the white arrow on the axis.
- "Disable" controls the stop of the rotation.
- **Click** "Back" to return to the F2 panel.



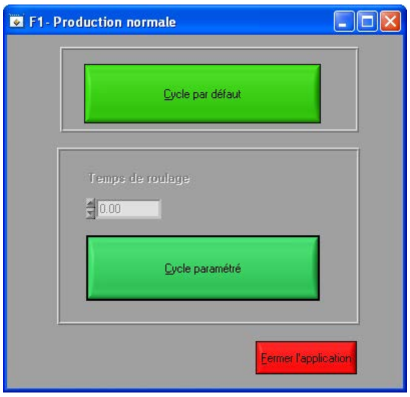
Consigne: 0.00

F 1.2 allows the measurement of speed and torque imposed by the PMSS. It is negative in receiver mode and positive in motor mode.



- The **Start** button starts saving the data.
- The **Stop** button stops recording.
- The **Clear** button clears the chart.
- The **Print** button saves the graphic as a .pdf file.
- Sliders are available to make the measurements.
- The **Exit Measurement** button closes the F1.2 panel and returns to the normal production F1 step.

3) Operation steps known as normal production.



These preliminaries contained in the preparation process carried out, allow access to the normal F1 production called Cycles in the F2 panel which offers two possibilities:

- **Default** cycle with a running time of about 17 seconds,
- **Parameterized** cycle whose duration is adjustable beyond 17 seconds.

The default test shall precede the parameterized test. The **Close Application** button allows the application to be output only after the set cycle.

3.1) Default cycle

Two panels appear:

- the panel "F1.1 - Energy balance",
- the panel "F1.2 - Measurements", already described above.

Just drag them to discover the panel covered. Careful! it is necessary to launch the acquisition as soon as the window is opened to see the torque and speed measured on the PMSM evolve.

F1.1 Energy balance

This panel represents the 7 elements of the test bench, from the power supply network of the SGMP to the battery.

Depending on the phases of the START-RUN-BRAKING cycle, arrows appear specifying the **direction of transfer of electrical or mechanical energy.**

The power grid plays the role of the fuel tank of a real GMP. An electrical resistor's mission is to dissipate the electrical energy returned by the SGMP converter in the restitution phases on the part of the SGMP. It compensates for the fact that the drive is not reversible in electrical energy to the network. This resistance simulates braking due to the friction of a vehicle or even its mechanical brake.

Nb d'essais 0 / 0

After a timeout, the cycle starts and lasts 17 seconds.

APPENDIX 4: GEMMA

Gemma :