**Polytech'Orléans**

**p o l y t e c h n i q u e**

***Institut***

***de l’université d’Orléans***

# Master AESM

Direct current engine

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**1stsemester**

*Bruno Bonheur*

**1 Thermal aspects**

* 1. **Aims of this chapter**

We will first of all consider these thermal aspects, which depend on the severity of efficiency demands.

It’s easy to take a larger engine to protect it against heat checking but this will increase the system cost. Sometimes this doesn’t matter because the additional cost is negligible compared to the total cost of the system. In this case the first model, called S1 in French standards, is sufficient and provides a wide security margin.

In some other systems, however, such as robotics or machine tools or special embedded machines, the motorization must be calculated to correspond as closely as possible to the need.

In this case the third approach is the only possibility.

Between these two approaches, there is an intermediate one which offers a widely-used and sufficient method: this method assumes that mechanical events of the duty cycle are smaller than the thermal constants; only the RMS value of the torque needs to be considered.

**1.2 : The S1 service type**

Definition

The S1 service type corresponds to the maximum permanent operating mode that the device can support without compromising its service life. It corresponds to the thermal steady state, when the various points of the machine temperatures are stabilized.



For the choice of engine, the transitional regime is not considered. It is sufficient to check that the limit θr is less than .

In practice, engine catalogues provide the permanent torque corresponding to the maximum rotor temperature when the ambient temperature is referenced at 40 ° C.

So one simply selects the 1st motor whose nominal torque Tn is immediately greater than the torque of the application TE.



In the case of a different ambient temperature, it is necessary to correct the engine torque capacity.

To do this, it was noted in section 1.1 that the maximum torque of an engine is expressed as a function of the maximum variation in temperature between the maximum protection afforded by the insulation and the ambient temperature.

Thus 

Given that the engine chosen by nominal torque is proportional to the square root of the temperature difference, this equation can be simplified as follows:

Thus for θa given

and for 40 °C reference temperature 

Thus 

if θa > 40°C ⇔ 

🡯 🡭

value for the engine X catalogue value for the X engine at the reference temperature θa temperature

In this case, there is decommissioning of the engine.

Of course one must then check that the downgraded torque  is greater than the torque of the TE application.

**1.3 – Modeling service type S1**

It is interesting for what follows to give a specific meaning to **the rise time of the rotor temperature**.

The thermal model for the calculation of θt(t) is given below.

Mode of conductive heat transfer from the rotor to the stator in solids:

Fourier’s law   heat flux density vector [w/m²]

Convection in the air-gap and radiation between surfaces are neglected.

θr - θa = ∑Rth . P

🡭

This is the sum of the thermal resistance encountered on the path of the rotor to the ambient air.

This relationship reflects the rise in temperature after a very long time, since before transmitting power, the rotor heats under the following law:

W = m.c. Δθ → temperature difference

🡩 🡩 🡼 heat /kg

energy mass

The power involved is:

 with thermal capacity Cth

Thus, in the heating of a rotor, both terms coexist. While the rotor heats under the effect of internal losses, it exchanges with the outside world.

Hence the equivalent electrical scheme:



**Resolution in the S1** **case**

P = cste for t > 0



thus the general solution with Second Member:

 with 

Initial condition 

thus ** **

**1.4 Other service types**

**1.4.1 quasi-S1 :**

Real applications often differ from an ideal S1 regime.

Indeed, engine torque demand can vary (for example in robotics)

Example: the widely-used periodic intermittent service S3

The load is periodic with a period of Tcycle. The load is constant when it is present during N.



**Remark 1:**. The temperature θr does not reach its asymptotic value

3 τth > N.

**Remark 2**: The engine can therefore operate at higher loads than the S1 regime. This is common in robotics.

**Remark 3**: In general, it is necessary to know the law θr(t) to verify that θr remains below 

.

**Remark 4** : In many cases, the thermal time constant is much higher than Tcycle.

Example: τth for the engine LS160 is 40 minutes (Leroy Somer), Tcycle and N inputs can be in the order of a minute or seconds

This amounts to neglecting the variation Δθr in favour of the average value of <θr>

In this case, we calculate the average power dissipated in the engine. Thus



The average power is transmitted on a mechanical cycle by the Fourier form.

thus <θr> - θa = Rth <p>

or <θr> = Rth <p> + θa

Then we simply check that <θr> is less than  or that the dissipated power remains less than the nominal regime S1, denoted.

The power comes mainly from the original joule power, expressed in the form: 



**Naturally, this introduces the concept of RMS torque squared over the mechanical period Tcycle.**

As the Joule power <p> is bounded by the ability of the engine to evacuate heat, the effective torque value on the mechanical cycle is bounded by:

 called nominal torque Tn

**It is then reduced to the S1 case**.

We simply select the first engine in the catalogue for which the nominal torque **Tn** is greater than the **RMS** value of the torque of the application. That is:



It is necessary to correct if θa ≠ θ40°C as in the **S1** case.

**2 - General method of study**

**2.1 Transient analysis**

The ripple **Δθr** of the temperature **θr** can no longer be neglected. This is rarely the case.

It is therefore necessary to check thatθr is always less than



There is a transient regime that does not concern the study of

In that case, we consider the average value <p> as the load.

The number of periods needed to establish the permanent regime is not useful information and will not be dealt with in this course.

We will restrict our study to the steady-state regime of the rotor temperature wave θR. This requires studying the temperature difference ΔθR( time).

**2.2 Permanent phase analysis**

In this case the variable is θR from to on a scale between θa and or Δθ on a scale between 0 and.

The permanent phase means that θR begins at the same value as where it finishes

This is the case in the following figure:

This is studied using a first-order thermal model.



two phases exist :

➀ 

Note : .

➁ 

SGESSM in both cases 

SPESSM ➀ 

SGEASM ➀ 

The temperature depends on the initial conditions,

thus



thus, SPEASM ➀  Eq. 1

➁ SPESSM ➁ 

SGEASM ➁ 

En ηTcycle 

thus 

SPEASM ➁  Eq. 2

We now need to find the value of :

Applying this continuity property of the function Δθ with the two boundary points, this gives:

In ηTcycle



In Tcycle



We obtain two functions with two variables 



We then check that this temperature remains below 

**optional**

**2.3.– Case of the 2nd-order model : study of S1.**

In some engines that have been optimized for reasons of mechanical inertia, the rotor contains no iron. In this case, the rotor has a weak thermal capacity, i.e. it heats up very rapidly before losing heat to the stator.

In this case, the following model is proposed:



Cr = thermal capacity of the rotor.

Cs = thermal capacity of the stator.

Rthr = thermal resistance of the rotor to the stator

Rths = thermal resistance of the stator to the outside.



This system is linearized using the Laplace transform:



hence  provided that θr(0) = 0 et θs(0) = 0

after expansion, this gives :



with



and 

Study of the response at a power scale P, **S1 case**



thus 



by identification



hence





thus



AN :

Cr = 100 Ws/°C Cs = 103 Ws/°C

RR = 1,25°C/W Rs = 0,8°C/W

# P = 63 w

Rs+Rr = 2,05 °c/w

τ1 and τ2 are the roots of 







so 

θr tends to 130° but the calculation was carried out with θa null, so it must be corrected as follows:

* With a temperature of 25°C, the limiting temperature of the insulators will be 155°C i.e. class **F**.
* If θa is 40°C, then take a higher class, e.g. **H**

2 **– Summary of the thermal study:**

Three cases can arise:

a/ The operating mode is of the S1 type. The choice is therefore made based on the value of the speed and the required torque compared to the catalogue values.

**TnS1>TappS1**

b/ The operating mode is different from S1, but the periodicity of the cycle is much less than the engine thermal time constants. The choice of torque is therefore made by using the concept of RMS value calculated over the mechanical period of a typical cycle. The method a/ is applied to this RMS value.

**if τTH>>Tcycle then TnS1>**

c/ The operating mode is different from S1 and the time constants of the engine do not meet the above conditions. A time study of the hottest temperature point is required to check the constraint on the maximum temperature of the insulation.

**To calculate θr(t), one must check that θr<θisolant max with the model that is the best suited to the engine**

In all cases, it must be remembered that running a motor in an ambient temperature of more than 40 ° C is equivalent to downgrading the nominal torque of the engine selected. It is therefore necessary to ensure that operating mode chosen is relevant, following the rule given above.