Improvement of AECV motorization with double rotor electrical motors
Amélioration de la traction par utilisation d'une machine à double rotor.

D. Lemoine

Laboratoire d'Electromécanique de Compiègne
Université de Compiègne
B.P. 20529
60205 COMPIEGNE Cedex
tél : (33) (0)3 44 23 44 23
fax : (33) (0)3 44 20 48 15

Didier.Lemoine@utc.fr

Abstract :
The motorization of a vehicle needs to work at a constant power on a very wide range of speed. The space of the machines used for this application must also satisfy some rigid constraints. These requirements make difficult to use electric machines permanent magnets.
This explains why we have choosen to integrate two motor axes into a same machine. The two motor axes are connected to the wheel, and each motor axe provides one part of the working range. One of the advantages procured by this machine to two rotors is to answer features of torque required to low speed by the simultaneous feeding of the two axes.
After a presentation of this machine with double rotor, we present the various parameters which influence the dimensionnement. Then, while respecting the imposed constraints, we do the comparison of this machine type with the machines to magnets permanent peripherals what permits to put in evidence the advantages of the double rotor electrical motors.

Résumé :
La motorisation d'un véhicule nécessite une caractéristique de traction qui comporte une très large plage de fonctionnement à puissance constante. L'encombrement des machines utilisées pour cette application doit aussi satisfaire des contraintes sévères. Ces exigences rendent difficile l'utilisation de machines électriques à aimants permanents.
Nous avons apporté une amélioration en choisissant l'intégration de deux axes moteurs dans une seule machine. Les deux axes moteurs sont accouplés à la roue, et chacun des axes moteurs assure une partie du domaine de fonctionnement. Un des avantages procurés par la présence de deux axes moteurs est de répondre aux caractéristiques de couple exigées à basse vitesse par l'alimentation simultanée des deux axes.
Après une présentation de cette machine à double rotor, nous présentons les différents paramètres qui conditionnent son dimensionnement. Puis, en respectant les contraintes imposées, nous effectuons la comparaison de ce type de machine avec les machines à aimants permanents périphériques ce qui permet de mettre en évidence les avantages des moteurs à double rotor.

1 Introduction
The motorization of a vehicle requires a characteristic of traction [5] that includes a wide range of speed to constant power (fig. 1).
The domain of working is characterized by two limits in opposition :
- a limit to elevated torque that appears at the time of the difficult startings,
- a limit to elevated speed that corresponds to the maximal speed of the vehicle.

It is translated for the electric machine that assures the practice by a constraint of current to assure the starting torque and a constraint of voltage at the time of the displacement to maximal speed.

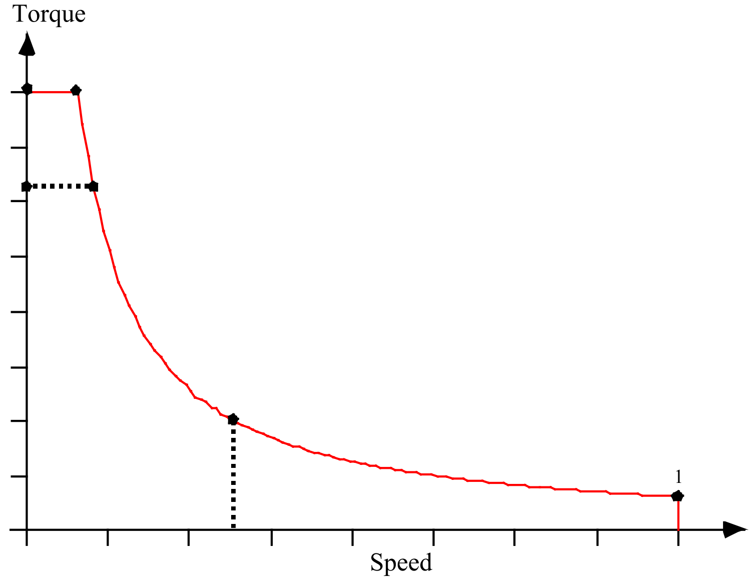

Fig. n°1 : range of working

There are few choices to solve and often implies to either over size the machine or to reduce the starting torque to decrease this constraint.
In order to be able to satisfy the set of these contradictory constraints we chose the integration of two motor axes in only one machine.

2 Description of the structure of the machine

This machine includes two distinct motor axes constituted by permanent magnets motors fed by trapezoidal currents [4]. These two motor axes are formed into a reversed structure. One is achieved by the association of a permanent magnets rotor inside a notched stator, and the other has an inversed structure, stator inside the rotor.
This second stator is sized to allow to place the first inside and so to limit the volume of the machine. A tube of material non-magnetic separates the two stators and allows their assembly (fig. 2).

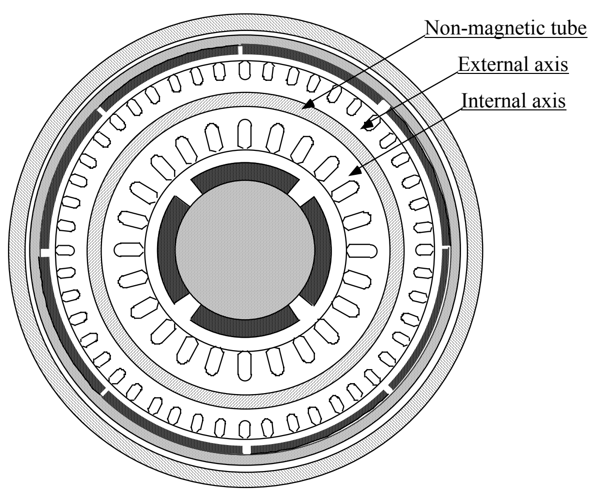

Fig n°2 : machine's cross section

The external rotor is mated directly to the wheel. The internal rotor is joined to the wheel through the intermediary of a gear-box. Every stator includes the windings fed by trapezoidal currents.
It allows to divide the range of working of the wheel in three parts :

- the high speed range delimited by the points 1-2 of the fig. 1,
- the intermediate speed range, points 2-3-6,
- the starting, points 3-4-5.

These three parts correspond to one way of working of the machine :
- the first is assured by the supply of the external axis,
- the second by the internal axis,
- and the last by the simultaneous supply of the them axes.

This three parts overlap avoiding to change their way of working when the load is situated on a limit.

3 Methodology of the dimensioning

This survey presents the results of machine dimensioning done with the help of analytic calculations [1],[2],[3].

The initial data are the limit speeds and the maximal power of the characteristic of the fig. 1. These data are completed by features of the supply and the properties of the materials constituting the machine : permanent magnet, ferromagnetic materials,…

A parameter of load distribution between the two axes defines distribution between the three ways of working previously described and allows to calculate the corresponding limit range. The choice of the gear ratio allows to deduct the ranges of working of each of the motor axes in them respective mechanical marks. These data are used for the calculation of the dimensions of each of the motor axes.

The procedure used for the calculation of the dimensions of the machine includes the following stages :

1 - calculation of the dimensions of the internal axis to assure its point of working to maximal speed,

2 - verification that these dimensions allow to get the working to torque maximum for the internal axis,

3 - calculation of the dimensions of the external axis to assure its point of working to maximal speed,

4 - verification that these dimensions allow to get the working to torque maximum for the external axis.

The stage 1 understands several iterations permitting to satisfy all constraints and features imposed. If the verification of the stage 2 is not satisfied, the dimensions are modified and the procedure restarts to the stage 1. These first two stages finished, the internal motor axis is dimensioned, the two stages 3 and 4 do a similar calculation for the external axis with as supplementary data the machine length equal to the internal axis length and the interior diameter of the external axis equal to the outside diameter of the internal axis increased of the thickness of the assembly tube.

This procedure of dimensioning has been used for the realization of a 3 kW machine [6].

With this machine we showed that :
- this structure allows to get the wide range of expected working,
- the simultaneous supply of the two axes provides the strong starting torque,
- the smoothing of the curve limits torque - speed.

4 Comparison

The double rotor electrical motor allows to get a working on a wide range of speed with a reduced space factor.

The table 1 gives the results obtained for the dimensioning of double rotor electrical motor on applications of traction of which the curve T=f(Ω) includes a range of working at constant power between 35 and 400 rpm.

Several machines are showed with the powers distribued between 3.75 kW and 60 kW.

We chose to present the current density in the conductors rather than the current. This choice is justified because the current density in the conductors is meaningful for the warming-ups of the machine, the current depends on the power of the machine.

Power	3.75	7.5	15	30	60	kW
D	0.246	0.294	0.349	0.408	0.485	m
L	0.205	0.240	0.294	0.368	0.470	m
Weight	56.0	94.6	167.3	296.8	560,0	kg
Internal axis current density	9.650	8.672	8.580	9.040	9.959	$10^6 A/m^2$
Enternal axis current density	14.054	13.005	12.200	11.406	11.160	$10^6 A/m^2$
Space	0.00974	0.0164	0.028	0.048	0.087	m^3

Table 1 : results for double rotor electrical motor

The constraint imposed on the outside diameter allows to be able to place the machine directly in a rim of vehicle with the gear-box overflowing toward the outside (fig. 3).

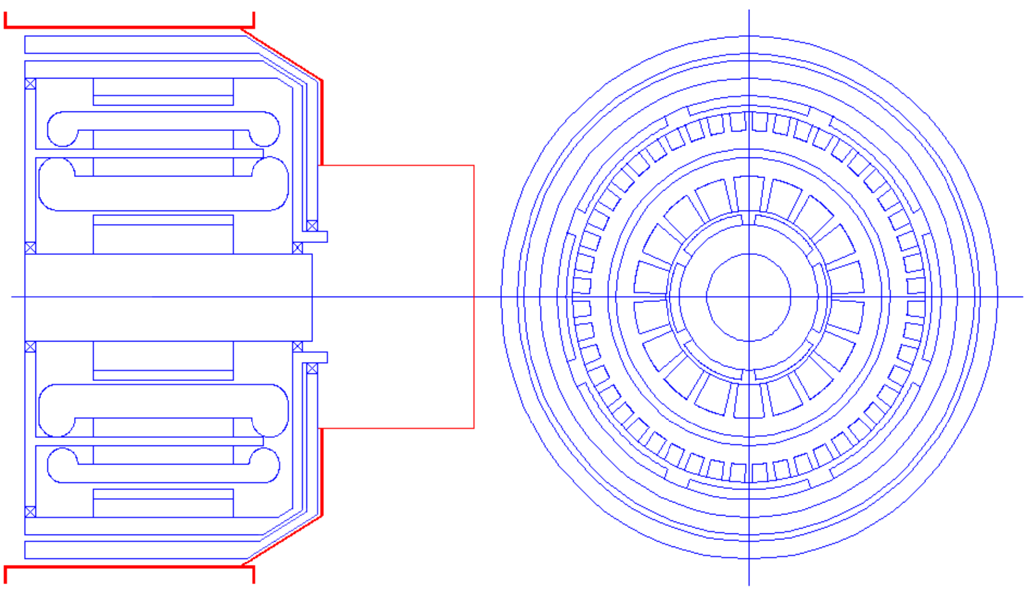

Fig. n°3 : machine's cross section with rim.

Let's compare the results obtained with the dimensioning of magnet permanent machines for the same application and in identical conditions of use.

The applications have the same curve T=f(Ω) and features of supply.

The procedure of dimensioning of these machines uses the same way of calculations that the one used for the double rotor electrical motor.

Power	3.75	7.5	15	30	60	kW
Weight	72.0	101.0	173.	290.	493.	kg
Current density	15.9	17.2	18.8	19.3	19.8	10^6 A/m^2
Space	0.0343	0.0330	0.0498	0.0732	0.0112	m^3

Table 2 : results for permanent magnet motors

The table 2 present the obtained results when we limited the current density in a machine with a value close to those of the double rotor electrical motors.

The curves fig. 4 and 5 represent the evolution of the weight of the machine and its volume in dependent of its power.

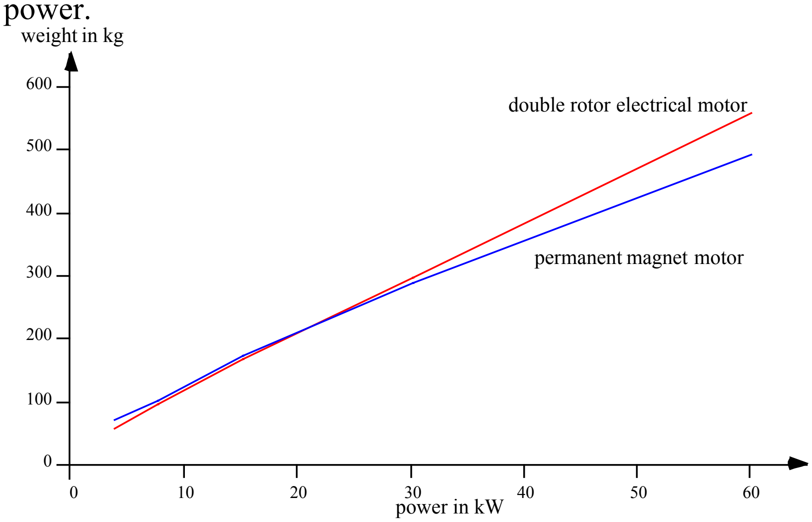

Fig. 4 : Weight versus power for double rotor motor and permanent magnet motor

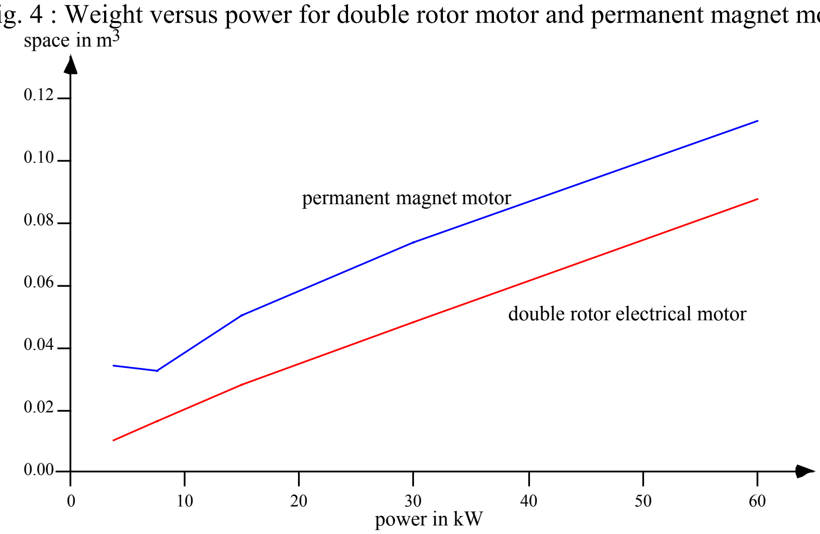

Fig. 5 : space versus power for double rotor motor and permanent magnet motor

The advantages of the double rotor electrical motor on the permanent magnets machine can be shown by the report of their weights and the report of their space factors (fig. 6).

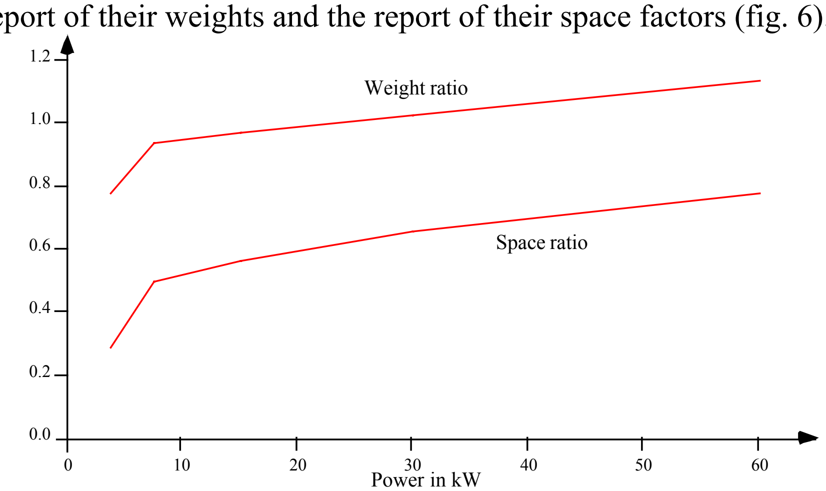

Fig. 6 : Weight ratio and space ratio

5 Conclusion

For the applications of traction to wide range of working the double rotor electrical motor allows to reduce the space factor considerably. This gain also results in a gain in weight for the power applications equal to 10 kW. Which means very important possibilities of use.
The mechanical realization difficulty can be compensated by this gain of space factor.
The advantages of this machine are not again of space, the double supply also allows a redundancy in use. Indeed, the possibility to work with the supply of only one stator winding allows a working on a reduced part of the range of fig. 1.
The choice of the parameter of load distribution between the motor axes modifies the position of the points of working to high values of density current, what also corresponds to the important warming-ups. In this survey this parameter has been chosen to equaly distribute the loads between the two motor axes. But the knowledge of the application must specify the loads applied in the torque - speed space as well as their working times, to choose the distribution of load limiting the warming-ups.

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