CONTACT-LESS ENERGY TRANSMISSION FOR MAGLEV

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ABSTRACT: High speed transportation systems (above 300 km/h), such as several Maglevs, cannot use anymore an electrical energy collector by catenary. A contact-less induction transmission becomes necessary. The proposed paper will first analyse the possible solutions for a permanent energy transfer system at any speed, including stationary. A model of the most efficient solution will be proposed. It will then be applied to the Swissmetro Maglev, in the case of motors on the ground. A specific software optimising the geometrical sizes, in particular the coil length, will be applied, in order to minimize investments and losses.

1. INTRODUCTION

Maglev transportation systems use two different electrical energy pick-up systems :

- Friction devices, classical or on the ground ;
- Contact-less induction principle.

In the last case, two realized solutions have been developed :

- The Transrapid system, using harmonics created by the slot variable permeance effect ;
- An auxiliary generator with a double coil system, on the vehicle, interacting with the track fixed coils, used on MLX (Fig 1)

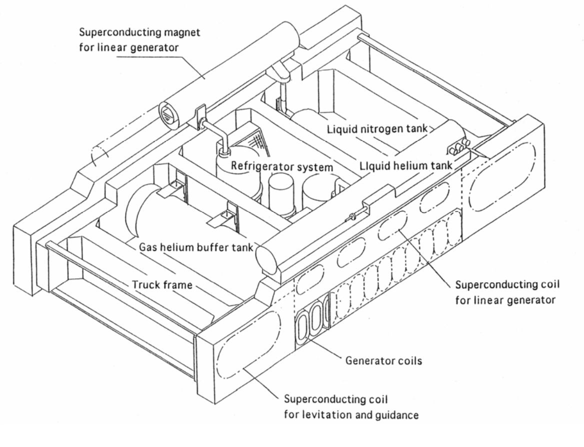

Figure 1: MLX double winding system for energy transmission

In both cases, if the solution is very simple and doesn't need any specific on-ground electronic device, the main drawback is the absence of energy transfer at standstill and low speed. The consequence is the necessity to have an important battery volume for these periods.

The presented solution, if needing more investment on ground is more simple on the vehicle, reducing its weight and volume. The present paper describes a modelisation and optimisation design process.

2. PRINCIPLE

The proposed principle is an ironless transformer with a fixed long coil with one turn and a secondary short coil with a number of turns depending on the required voltage.

The back EMF voltage in the secondary coil of a transformer is given by the following equations :

$$u_2 = N_1 N_2 . \Lambda_{12} . di_1/dt$$

For a sinusoidal current, the rms values are:

$$U_2 = N_1 N_2 . \Lambda_{12} . \omega . I_1$$

With:

u_2 = secondary voltage
N_1 = number of primary coil turns
N_2 = number of secondary coil turns
Λ_{12} = mutual permeance
= $\mu_0 . S_a / l_{eqa}$
μ_0 = vacuum permeability
S_a = winding air magnetic section

l_{eqa} = air equivalent length
i_1 = primary current
$\omega = 2\pi f$ = pulsation

Increasing ω allows to compensate the important reduction of Λ_{12} from iron magnetic circuit to air. It is also possible to increase the coil magnetic section S_a to compensate this effect.

Such a transformer can be represented by its equivalent scheme (Fig 2).

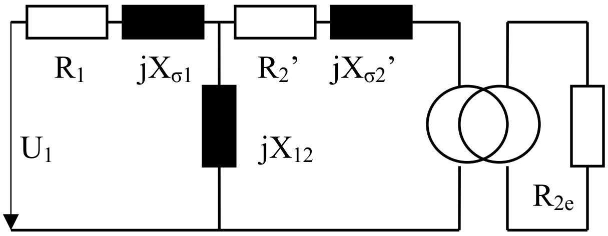

Figure 2: Air transformer equivalent scheme R = resistance, X = reactance

3. DESIGN PARAMETERS

The main design parameters are geometric : the coil lengths, widths, sections and their distance or air gap.

The number of turns is chosen equal to 1 (n_1 =1) for the primary fixed coil, which corresponds just to one closed loops.

The number of turns for the secondary coil depends on the wished voltage.

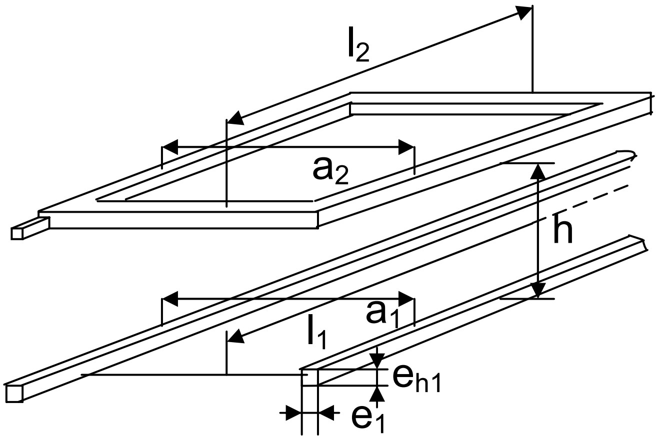

Figure 3: Energy transfer system – Coil geometry.

Thus, the main parameters defined by Figure 3 are:

- l_1 = primary coil length
- l_2 = secondary coil length $l_1 >> l_2$
- a_1 = primary coil width
- a_2 = secondary coil width
- e_1 = coil section width
- e_2 = coil 2 section width
- e_{h1} = coil 1 section height
- e_{h2} = coil 2 section height
- d = distance between coils
- n_1 = primary coil number of turns = 1
- n_2 = secondary coil number of turns = 1

4. DESIGN METHODOLOGY

To design such energy transfer system, the following steps are applied :

- Determine the transformer parameters as a function of the geometry ; reference Macabrey 1998 is mainly used in the case of rectangular coils.
- Determine the function “cost” to minimize. It could be the losses, the copper volume, etc.
- Determine the constraints to impose, such as some geometry limits, number of turns, voltage range, etc.
- Research the set of solutions minimizing the cost function. The Software Pro@DESIGN (Reference) as been used in this application.

5. APPLICATION

The application is based on the following data :

P_u = useful power transferred = 500 kW

U_1 = 12’000 V

$a_1 = a_2$ = 1 m

l_2 = 20 m

d = 0,02 m = 20 mm

Moreover, some parameters are imposed :

- The primary current density = 2 A/mm²
- The secondary current density = 1 A/mm²

The main results obtained are :

Primary copper section	358 mm²
Secondary copper section	264 mm²
Primary coil length	122 m
Efficiency (transformer only)	98.44%
Primary copper losses	7.04 kW
Secondary copper losses	0.886 kW

Turn number of secondary coil	2
Secondary voltage	1900 V
Frequency	12300 Hz

6. PARAMETRIC ANALYSIS

The software Pro@DESIGN allows to calculate a parametric sensitivity in order to show the main tendencies.

In Figure 4, the transferred power P_u is represented as a function of the distance d between the coils, from 10 to 30 mm, with a relatively low variation for a constant load resistance.

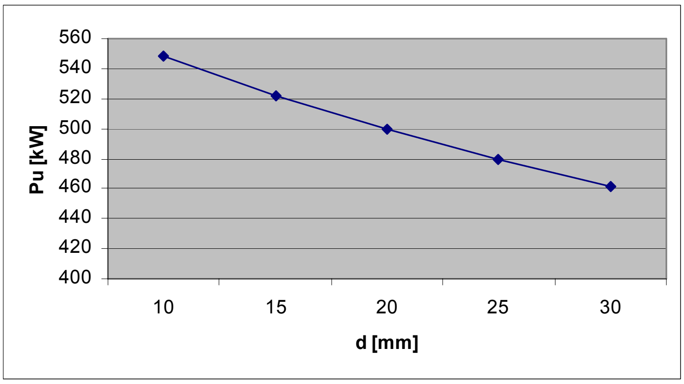

Figure 4: Transferred power as a function of coil distance d.

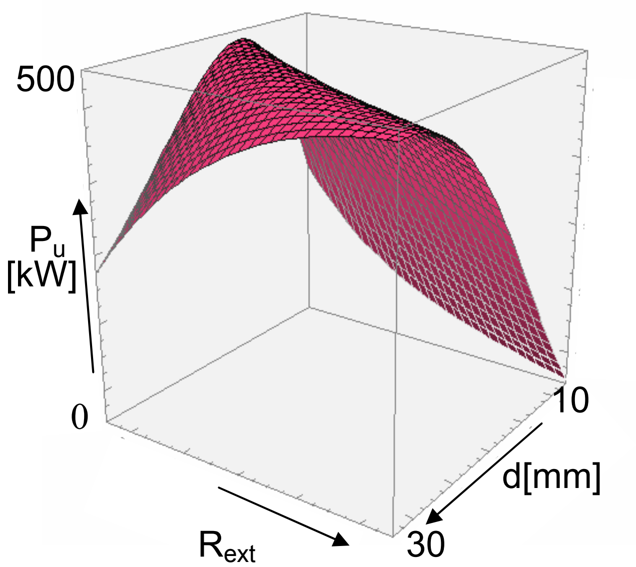

Figure 5: Transferred power as a function of coil distance d and external load

Figure 5 shows a 3D picture, corresponding to the load R_{ext} adaptation with a gap between 10 and 30 mm. It is so possible to maintain the power at 500kW.

Figure 6 presents the influence of the primary coil length l_a on the transferred power, with a constant load. An important reduction occurs with the length increase. A transferred power of 500 kW remains possible until 320 m, with a frequency and load adaptation.

Figure 7 shows the variation of power as a function of the load $R_{ext.}$

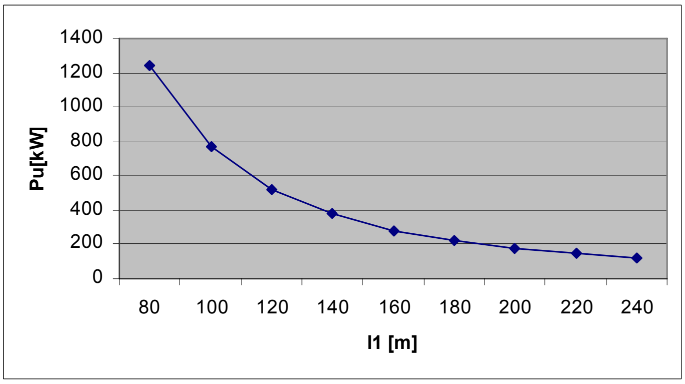

Figure 6: Transferred power as a function of primary coil length l_1 .

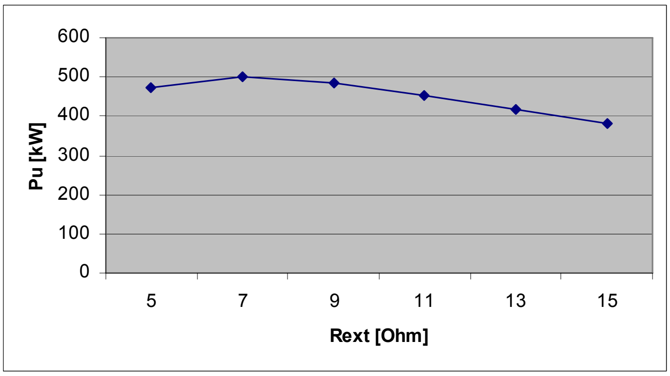

Figure 7: Transferred power as a function of external load R_{ext}

Figure 8 describes, in a 3D form, the influence of frequency and load on the transferred power P_u. The plane with a value of 500 kW is represented.

Figure 9 shows the corresponding variation of efficiency (very small, from 98.5% to 98%) corresponding to powers from 500kW to 200kW.

Figure 10 presents the efficiency variation as a function of the distance between the coils, from 10 to 30mm, (very small, from 98.52 to 98.35%).

Figure 11 shows the effect of the primary length l_1 on the efficiency, which varies from 98.85% with 80 m to 97.15% with 240 m.

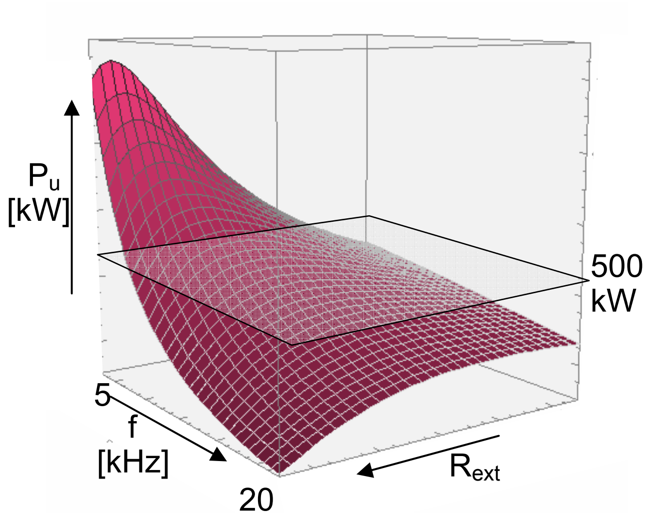

Figure 8: Transferred power as a function of external load R_{ext} and frequency f.

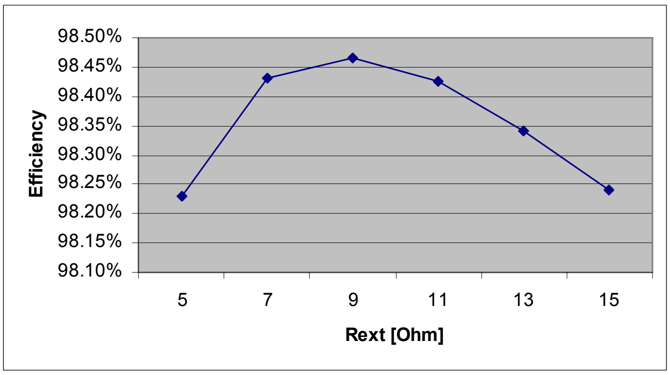

Figure 9: Efficiency as a function of external load R_{ext}.

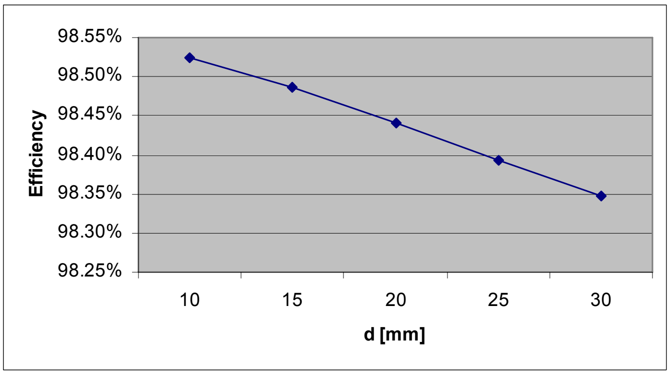

Figure 10: Efficiency as a function of coil distance d.

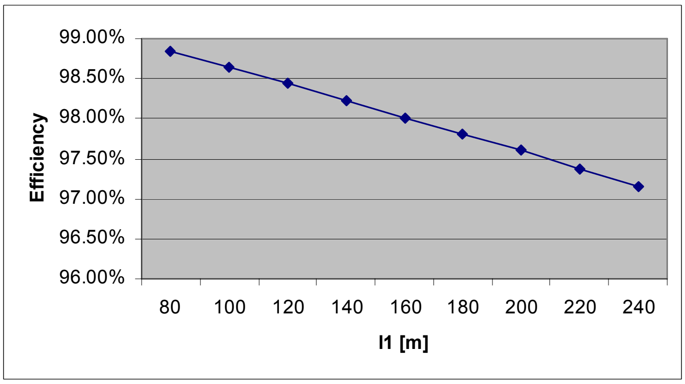

Figure 11: Efficiency as a function of primary coil length l_1.

Figure 12 shows the influence of the secondary number of turns on the transferred power for 1,2 and 3 turns.

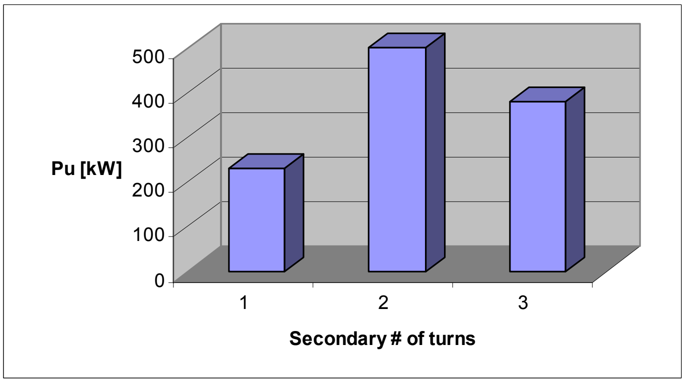

Figure 12: Transferred power as a function of secondary coil turn number.

All these parametric studies give information on a final choice and sensitivity to parameters varying in operation, such as coil distance d and load resistance Rext.

7. CONCLUSION

The presented solution, if more expensive than those used for Maglev such as Transrapid and MLX, have the advantage to assure the transfer at any speed, including standstill and so to spare an important weight of batteries.

The described model, introduced in an efficient optimization software Pro@DESIGN, is very flexible and efficient to choose the different parameters.

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Pro@DESIGN, Design Processing Technology, ttp://www.designprocessing.com/