"DESIGN OF HIGH EFFICIENCY INDUSTRIAL INDUCTION MOTORS BY INNOVATIVE TECHNOLOGIES AND NEW MATERIALS"

EXECUTIVE SUMMARY

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Aim of the project

This project consists of the efficiency improvement in industrial three-phase induction motors, in the 0.75÷22 kW range, making use die cast copper rotor cages and most suitable magnetic materials (high permeability and/or low loss).
The aim of the project is the analysis and the construction of several prototypes of induction motors by using the above mentioned innovative technological solutions, in order:
- to define the design procedures and design strategies;
- to verify the actual efficiency improvements;
- to verify the arrangement of the motors respect to the European Classification Scheme (CEE-CEMEP) that foresees three efficiency classes EFF1, EFF2 and EFF3.

Research description and results

In this project three important Companies have been involved:
- ThyssenKrupp Electrical Steel AST (Acciai Speciali Terni), European leader in the production of electrical steels for electromechanical applications. Acciai Speciali Terni has provided several electrical steels that have been used in the new prototypes.
- LAFERT S.p.A., one of the most important Italian manufacturer of induction motors. LAFERT has provided the stator and rotor cores and stator windings and has assembled the prototypes with copper rotor cages. Moreover, LAFERT has co-operated in the construction of new stator and rotor figures and tests on the motors.
- FAVI (Fonderie et Atelier du Vlmeu), French company specialized in copper alloy pressure die-casting. Its experimentation on copper rotor cage die casting started three years ago. FAVI has co-operated manufacturing a line of expensive high-temperature moulds and several copper rotor cages.

According to the research program, three different sizes in the range 0.75-22 kW have been chosen, together with LAFERT S.p.A., and particularly: 3 kW - 4 pole, 7.5 kW – 4 pole and 15 kW – 4 pole.
The "reference" designs with aluminum cage and standard electrical steel (8050 by ThyssenKrupp Electrical Steel AST) are made by LAFERT S.p.A. and they belong to the low efficiency class EFF3.
The following high performance electrical steels have been chosen together with AST and LAFERT S.p.A.:
- low loss electrical steels: 5350, 4750, 3350 and 3150;
- high permeability electrical steels: 8050 H, 5350 H and 3550 H.

The following design strategies have been investigated:

a) substituting copper cage for aluminum cage and standard electrical steel 8050, without changing any motor dimension (solution with no additional cost);
b) substituting copper cage for aluminum cage and high performance electrical steel, without changing any motor dimension (solution with low additional cost);
c) design optimization of copper cage motor with low additional cost, by changing the stator winding and the stack length only (design strategy S1);
d) design optimization of copper cage motor with medium additional cost, by changing the stator winding, the stack length and the stator and rotor figure (design strategy S2);
e) design optimization of copper cage motor with high additional cost, by changing the stator winding, the stack length, the stator and rotor figure and the diameters (design strategy S3).

The solutions (a), (b) have been employed for all the considered sizes, while the solutions (c), (d) and (e) for the 3 and 7.5 kW only.

An accurate preliminary analysis, by a specific software, has been carried out that allowed to evaluate, in advance, the better and "final" design solutions. The results concerning theses simulations can be synthesized as follows:

- the substitution of copper cage for aluminum cage allows to obtain designs in the EFF2 efficiency class but not in the EFF1. The use of high performance electrical steel allows to move towards the EFF1 class for the 15 kW only.
- the design strategy with low additional cost (S1) and the use of high performance electrical steel allows to move the 3 kW motor towards the minimum efficiency level of the EFF1 class; the 7.5 kW size remains in the EFF2 class.
- the design strategy S2 (new stator and rotor figure without changing the diameters) allows to reach fully the EFF1 class for the 3 kW only, while for the 7.5 kW it is necessary to increase the outside stator diameter (high additional cost S3).

The results of this preliminary analysis have allowed to start the next step concerning the construction of the prototypes.
First of all, the most suitable electrical steel has been chosen. This choice has been done with reference to the material performance (loss/permeability) and hardness (HRB).

Electrical steel	Hardness (HRB)
8050	61
8050 H	58
5350	66
5350 H	66
3350	75
3150	75

According to the LAFERT S.p.A. suggestions, the electrical steels with hardness higher than 66 have been excluded: then, the high permeability material 5350 H has been chosen. Moreover, a further low loss electrical steel (4750) has been tested, in order to evaluate the effect of this type of material on the motor performance.
ThyssenKrupp Electrical Steel AST has provided to LAFERT S.p.A about 6000 kg of 5350 H, 6000 kg of 8050 and 100 kg of 4750..
Then, LAFERT S.p.A. has sheared the steel and realized the new stator and rotor cores and the new stator windings. The rotor cores have been sent to FAVI for the die casting copper process: for this step, FAVI has arranged 5 different moulds.

The prototypes have been assembled and tested by LAFERT S.p.A.. Moreover, 3 standard motors with aluminum cage and 8050 electrical steel have been tested (one for each size), and assumed like as “reference motors” for the evaluation of the efficiency improvements.
The efficiency has been evaluated with reference to the following methods: Direct, IEC 34-2, IEEE 112 B, IEC 61972-2 (this not yet acting). Accurate results has been obtained with IEEE 112 B and IEC 61972-2 methods, with a very low differences. The experimental results presented in this Report refer to the IEC 61972-2 method.

The first series of prototypes has been realized, for the 3 sizes, by substituting copper rotors for aluminum rotors only. In order to evaluate the effect of the copper cage on the motor efficiency, the comparative tests between the “reference” motor and the prototype has been carried out by adopting the same stator core and winding: in this way any difference due to the production process has been avoided.
This first design solution has allowed to move all motors in the EFF2 class.
The efficiency improvements are not uniform for all the sizes and vary from 1.5 points for the 3 kW to 3 points for the 7.5 kW. For the 15 kW it is interesting to remark that the tolerance on the new efficiency could classify this motor like as EFF1.
The use of the 5350 H electrical steel does not give rise any further movement (from EFF2) for the 3 kW and 7.5 kW, while the 15 kW reaches the EFF1 class (without tolerance). For this reason no further solution has been adopted for the 15 kW motor.

The design strategy with low additional cost (S1) has concerned the increase of stack length, a new stator winding and the use of the copper cage. The new motors has been designed by a suitable software that combines the analytical procedure and the optimization algorithm.
This design strategy, and the next ones, has involved the 3 and 7.5 kW sizes. The increase of the stack length is consistent with the standard housings.
For the 3 kW, three series of prototypes has been realized, with the following electrical steel: 8050, 5350 H and 4750. The efficiency is 4 points higher than the “reference motor" one, and this improvement increases from 8050 to 4750. The new motors remain in the EFF2 class, but could be labeled EFF1 motors if the tolerance is taken into account.
For the 7.5 kW, only the series with 5350 H electrical steel has been realized. The efficiency improvement is about 4 points respect to the aluminum “reference motor” but the motor remains in the EFF2 class and it can not be labeled EFF1 if the tolerance is taken into account.

The full motor re-design (solution S3) has been diversified for the 3 kW and 7.5 kW sizes: in fact, the design optimization of the 3 kW has allowed to reach the EFF1 class without changing the diameters (solution S2). Unfortunately, for the 7.5 kW has been necessary to increase the outer stator diameter (high additional cost S3). The new motors has been designed by the same software that combines the analytical procedure and the optimization algorithm.
The new stator and rotor figures have been realized by two punches made by Fratelli Perego, while the LAFERT S.p.A. has cared the shearing and motors assembly. FAVI has carried out the die cast copper rotor cages. In order to avoid two new moulds for the die casting process, the stack length of the new motors has been chosen equal to the design strategy S1 one (in the previous step).
The experimental tests on the new prototypes are on going.

During this project, more than 50 prototypes have been made, that have been grouped in 15 series, and 5 moulds for the die casting process: 18 experimental tests have been done, one for each series, and 3 tests for the “reference motors" with aluminum rotor cage.

References

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