UNIVERSITY OF CRAIOVA
IN ELECTROMECHANICS, ENVIRONMENT
AND INDUSTRIAL INFORMATICS ENGINEERING

OPTIMIZATION OF DESIGN TOPIC AND INDUCTION MOTOR DESIGN FOR RAILWAY TRACTION

- Abstract -

PhD Student: Eng Mihail RĂDULESCU

Coordinator: Professor Aurel CÂMPEANU

Craiova
- 2010 -

CONTENTS

This paper is primarily aimed at identifying the main parameters specific in the use of asynchronous machines for traction.

It was primarily intended to achieve a substantial theoretical definition and analysis of induction machine operation. Second, an induction motor was designed for rail traction, emphasis on optimizing the design and practical integration in an appropriate existing gauge bogie.

The phenomena of asynchronous machine and its behavior when powered by converters were analyzed by simulation. As far as the machine operation is closely linked to the vehicle, the machine design was based on the conditions of the vehicle.

The paper is structured in seven chapters and covers the whole area of concern in the field, the practical achievements in Romanian and abroad up to the theoretical analysis of asynchronous machine operating regimes.

Chapter 1. CURRENT STATUS IN THE USE OF ASYNCHRONOUS MOTORS FOR ELECTRIC TRACTION

Electrical drives with induction motors on railway vehicles established the best available technical solution for most aplications, widely known until now on the railway traction market. Since the 70s, many vehicles and types have shown the advantages of induction motors and electronic converters drives against the 'conventional' DC motors.

Traction takes place under particularly heavy burden because traction is very variable, even on the same train, because of gradients, curves, stops and starts. Therefore, the electric motor must have a high overload capacity to cope with traction.

Traction motor, axle or motor wheels and mechanical transmission design is a complex whole, the actual transmission parameters, electrical parameters and mechanical construction of the traction motor are mutually interdependent. The construction of these elements is defining the traction vehicle and is determined by a number of important elements, such as how the axle is driven by the motor, what is the positioning mode of the traction motors on the vehicle and how the weight of the motor is loading the driving axle. The modern solutions related to the up to date requirements came as a result of the analysis.

Depending on how its weight is taken by the driving axle, the traction motor is built as:

- Not suspended motor,
- Semisuspendat motor,
- Completely suspended motor.

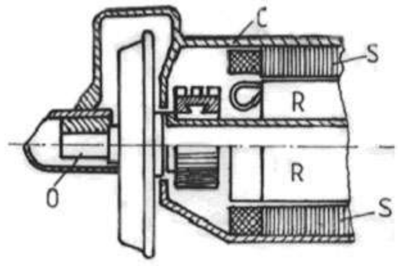

Figure 1. Engine thrust not suspended. longitudinal section;
O - axle; R - rotor; S - stator; C - casing

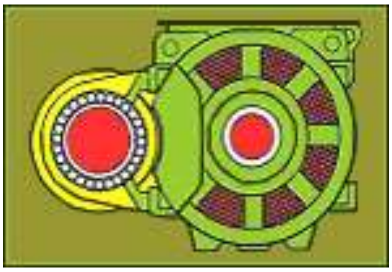

Figure 2. Semisuspendat motor transversal section

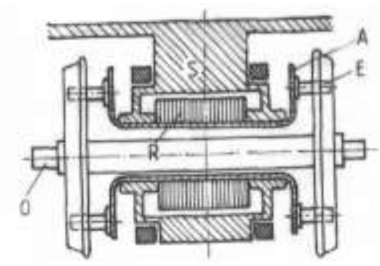

Figura 3. thrust engine suspended thrust engine suspended:
O - axle; R - rotor; S - stator;
A – hollow shaft ; E – rubber joint

Thus, the fully suspended motor solution is used in particular for higher running speed greater then 160 km / h. The transmission can be done by cardan system, too, method that allows torque transmission changing axis with respect to the vehicle motion.

Chapter 2. STATIC CONVERTERS

In this chapter converters supply systems of induction motors are described and analyzed. Static converter is a revolutionary element which allowed the induction machine, whose characteristic is rigid, to become the main tool used in railway traction. After presenting the types of converters, and control methods, the manner to control the output voltage is discussed. Among the modulation methods the sinusoidal pulse width modulation is analyzed in term of sinusoidal modulation, known as the submodulation principle, and also the precalculated modulation aiming selective elimination of harmonics, reducing losses and torque pulsations.

To reduce harmonics that appear at the inverters output in traction a multilevel inverter type is proposed, which guarantees an inverter voltage waveform close to sinus. In the final chapter the main parameters of traction converters are examined.

Chapter 3. CHARACTERISTICS OF DEFINITION FOR THE INDUCTION MOTOR IN TRACTION

The performances of the speed control of the induction machine are analyzed in terms of sustained flow in the air gap. To express the mathematical model of asynchronous machine an operating principle expressed by equations is presented. Rotor equations are written considering both the steady state and rotating state and the equivalent induction machine schematics are presented. An important part of this chapter is the electromagnetic torque and mechanical characteristics. Induction machine speed control essential for railway traction has been addressed both mathematically - with equations and diagrams - and in terms of its connection with voltage and frequency converters. Speed control was realized by changing the supply voltage frequency, thus achieving a change in synchronization speed so, depending on torque load, the rotor speed changes.

Chapter 4. FEASIBILITY STUDY ON MODERNIZATION OF DIESEL ELECTRIC LOCOMOTIVE

In the development of railway traction vehicle construction, consistently two main trends occure: increasing the installed power as result of the increased demand for higher speed and tonnage and reducing vehicle weight. Analyzing the Romanian situation in terms of availability of its locomotives, in terms of consumption, and cost of maintenance, upgrading the existing fleet is the best solution in short term. Considering the technical data of the locomotive to be upgraded with the towing performance requirements, from the power balance of the locomotive resulted the rated and maximum torque, the rated and maximum power, the rated and maximum speed and the traction force diagram.

Chapter 5. OPTIMUM DESIGN OF THE TRACTION INDUCTION MOTOR FOR MODERNIZED DIESEL ELECTRIC LOCOMOTIVES

The effective design methodology of a railway traction induction motor, must satisfy: functional tests, the achievement of certain technical features required by the customer, the safety criteria, providing a safe behavior of the machine operating in normal conditions and short-term overload, the economic criteria for the achievement of the machine at a minimum total cost taking into account both construction and operational expenses.

After accomplishing the design of a classical induction machine in this chapter an optimization method is proposed as a criterion in determining the unequivocal best constructive solution in the manufacture of electrical induction machines for general purpose. The method is presented and analyzed in the case of a symmetrical three-phase induction machine with constant air gap.

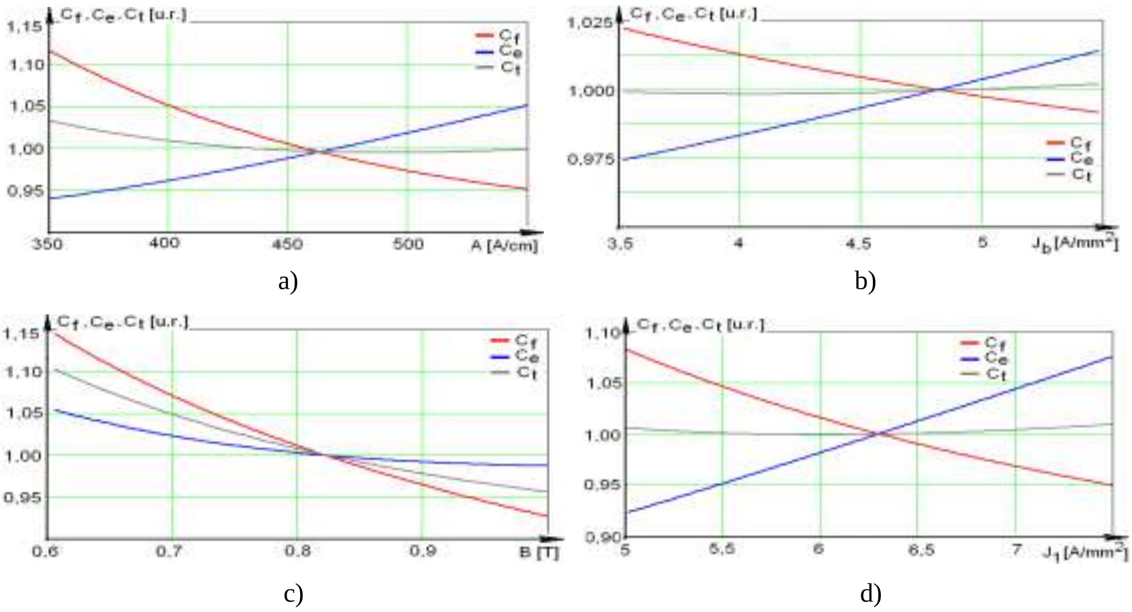

Figure . 4. Curves of variation of cost in relation to variables analyzed:
a) Current Blankets b) The air gap magnetic flux density;
c) and d) Current density of stator and rotor windings.

The optimal design of induction motor traction was based on the optimization study with respect to all variables A, B, J1, Jb simultaneously considering the four criterion variables and the minimum total cost. The objective function, the objective function variables and its restrictions were used to optimize the induction machine.

Inside the simulations and experimental results subsection, considering its operation in no load, in short circuit and in load, the motor characteristics are determinated by numerical methods. Of major importance is the analysis of induction motor reaction powered by a voltage (and frequency) fed static converter. Numerical analysis was performed for the distorting regime, where the induction motor was powered from a voltage and frequency static converter, and theoretical results were compared with those determined under experimental sinus environment.

Chapter 6. EVOLUTE MATHEMATICAL MODELS TO SIMULATE THE DYNAMIC BEHAVIOR OF THE DESIGNED TRACTION MOTOR

In this chapter the results of simulations that allow significant behavior predetermination of traction motors in certain dynamic processes are presented and interpreted. The analysis is of practical nature, so that constructive solutions designed for the optimum traction motor fulfill the requirements of the recipient.

From the entire analysis of the dynamic processes in their quasi-steady stage, a good correspondence with the optimal design is revealed. The chapter is split in two. In the first part advanced dynamic mathematical models of saturated induction machine starting in different circumstances are analyzed, while the effect of inertia on the characteristics is studied, and in the second part electromagnetic and mechanical stress checkings were performed under particular dynamic regimes of the designed induction motor.

The comparison between the quantitative results obtained by dynamic simulations and those offered by electromagnetic design calculations yields a good correspondence which suggests that the traction motor is well sized considering all the circumstances that may occur in service.

Chapter 7. CONCLUSIONS AND PERSONAL CONTRIBUTIONS

By optimizing the design of asynchronous machine program with the introduction of specific conditions of railway traction, using methods and criteria for optimization with modern systems of calculation and simulation, the paperwork succeeded to improve the design and finally succeeded to achieve efficient induction motors to the satisfaction of the modern rail operators.

A few contributions in this paper can be mentioned:

- An objective analysis of developments in asynchronous traction motors in terms of contemporary conditions;

- A study of stationary optimization methods and criteria used in designing of usual electrical machines;
- Identifying of specific restrictive conditions for traction motors supplied by static converters;
- Achieving of an uniform analysis of the phenomenon in asynchronous machine and achievement of complex mathematical models;
- Static and dynamic efficatious inductance calculation and graphical representation with respect to the magnetization current, in order to see the influence of magnetic saturation on specific dynamic regimes of the locomotive;
- Implementation of programs for analysis in steady state applying to any motor together with a program to determine the motor parameters. With these programs any induction motor can be analyzed and the obtained parameters can be used for field oriented control;
- No load starting analysis both in the nominal torque and the torque required by the customer, mainly focused on extreme values of torque, current - amplitude and duration;
- Other major conclusion concerns the fact that if very large moment of inertia simulations are performed, the dynamic mechanical characteristics can be confused with the static imechanical caractertistics exempting the first moments of starting,

The ANNEX presents experimental measurements and bench assembly drawing of a similar induction machine used in practical experiments.

SELECTED BIBLIOGRAPHY

1. ABB HENSCHEL, *Traction Vehicle Technic for all Application*.

2. Appelbaum J., Fuchs E. F., White J. C. - *Optimization of three-phase induction motor design, part. 1: Formulation of the optimization technique,* IEEE Trans., 1987, EC-2, No.3, p.407-414;

3. Appelbaum J., I.A. Khan, E. F. Fuchs, J. C. White - *Optimization of three phase induction motor design, part 2: The efficiency and cost of an optimal design,* IEEE Trans., 1987, EC-2, No.3, p.415-422;

4. Bălă C. - *Maşini electrice*, Ed.Didactică şi Pedagogică, Bucureşti, 1982.

5. Bandyopadhyoy M. N. - "Optimization techniques in electrical machine design", J. of the Institution of Engineers, vol. 73, no. 12,pp. 83-91, Jun. 1992.

6. Belatel M. and Benalla H. – "*A Novel Approach to Design Ventilation Ho les in Machines by Finite Element*", ISESC'05 Conference, Algeria, 2005.

7. Belatel M. and Benalla H. – "*Optimization of Stator Slots Geometry in Synchron*", CEE'05 Conference, Portugal, 2005.

8. Bin Wu – *Presentation material exctracted from „High Power Converters and AC Drives"*, IEEE Press/Wiley November 2005, ISBN: 0-4717-3171-4.

9. Burdubuş, Fl**.** - *Construcția şi proiectarea vehiculelor de tracțiune cu motoare electrice*, Reprografia Universității din Craiova, 1998.

10. Câmpeanu Aurel – *Maşini electrice. Probleme fundamentale, speciale şi de funcționare optimă* – Ed. Scrisul Românesc , Craiova, 1988.

11. Dordea Toma - *Maşini electrice*, Ed.D.P, Bucureşti, 1977

12. Dordea Toma, Biriescu M., Liuba Gh., Madescu Gh., Moț M – *Maşini elctrice. Parte complementară,* Ed. Orizonturi Universitare, Timişoara 2002.

13. Electroputere SA. - Type Test Report No. 1124/0.109.2009.

14. Fu W. N., Ho S. L. and Wong H. C. - "*Design and analysis of practical induction motors*", IEEE Trans. on Magnetics, vol. 37, no. 5, pp. 3663-3667, Sep. 2001.

15. Huang H., Fuchs E. F, Zak Z - *Optimization of single-phase induction motor design. Part 2: The maximum efficiency and minimum cost of an optimal design,* IEEE Trans. Of energy Conversion, vol.3, no.2, June 1998, p. 357-366.

16. Lai H. C., P. J. Leonard, Rodger D. and Allen N. – "*3D Finite Element Dynamic Simulation of Electrical Machines Coupled to External Circuits*", IEEE Trans. on Magn, Vol. 33, No. 2, pp. 2010-2013, March 1997.

17. Liu X. and Slemon G. R - "*An improved method of optimization for electrical machines*", IEEE Trans. on Energy Conversion, vol. 6, no. 3, pp. 492-496, Sep. 1991.

18. Madescu G., Boldea I., and Miller T. J. E. - "*The Optimal lamination approach to induction machine design global optimization*", IEEE Trans. on Industry Applications, vol. 34, no. 3, pp. 422-428, May/Jun. 1998.

19. Mohammed O. A. , Üler G. F. and Koh C. S. - "*Design optimization of electrical machines using genetic algorithm*", IEEE Trans. On Magnetics, vol.31, no. 3, pp. 2008-2011, May 1995.

20. Nurdin M., Poloujadoff M. and Faure A. - "*Synthesis of squirrel cage motors- A key to optimization*", IEEE Trans. on Energy Conversion, vol. 6, no. 2, pp. 327-333, Jun. 1991.

21. Sames M. - "*Optimization of induction motor design*", Zeszyty Naukowe Politechniki Slaskiej Seria Elektryka, z. 176, pp.103-110, 2001.

22. SIEMENS. Die Universal-Lokomotive fur Europa. Prospect.

23. Vlad I., Enache S., Alexandru D.: *Utilizarea metodelor numerice în proiectarea maşinilor electrice de trațiune*, Ed. SITECH, Craiova, 2000.

24. ***: Matlab Reference Guide, The math Works, Inc. Natick, Massachuseths, 1992.

25. ***: Matlab User's Guide, The math Works, Inc. Natick, Massachuseths, 1992.