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Manufacturing of IE4 Super Premium Squirrel-Cage Induction Motors at S.C. Electroprecizia Electrical Motors S.R.L. Săcele

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Abstract
Reducing electricity consumption is one of the actual requirements nowadays, being triggered by both rising energy prices and climate change effects. As electrical motors are significant energy consumers, their efficiency should be increased for lower consumption. In this regard, efficiency classes such IE4 were developed. The current paper presents the actions performed by S.C. Electroprecizia Electrical Motors S.R.L. Săcele to increase the efficiency of the induction motors that they manufacture to comply with the stricter requirements in terms of efficiency. Information is provided about the technical solutions that were used and the results for two pole pairs motors with rated powers of 1.5 and 3 kW.

Keywords
squirrel-cage induction motors, losses decrease, super premium efficiency

1. Introduction

There is a keen interest at European Union (EU) level in reducing both electricity consumption and greenhouse gases by 2030. In this regard, importance is given to efficiency of the electrical motors, as they consume 70% of the total electric energy produced in the EU. The IEC 60034-30-1 standard, issued by the International Electrotechnical Committee (IEC), establishes four efficiency classes for electrical motors: IE1 (Standard), IE2 (High), IE3 (Premium) and IE4 (Super Premium) [1]. Regarding the efficiency determination of electrical motors, there are still no standardized procedures in this regard. One popular method for efficiency calculation is Method B from IEEE 112 standard. Alternative methods to compute the efficiency of induction motors have been developed, being analysed in [2]. But the use of various methods can lead to different results in case for the same motor, as have shown the authors of [3, 4]. One explanation might be the linked to difficulty of estimating the supplementary losses.

The present paper is dedicated to the manufacturing of squirrel cage induction motors to fulfil the requirements of IE4 efficiency class. The nominal efficiency values for the IE4 class, according to IEC 60034-30-1, for the motor's portfolio of by S.C Electroprecizia Electrical Motors SRL Sacele are presented in Table 1.

Table 1. Nominal efficiency values for IE4 class, at 50 Hz

P_N (kW)	Efficiency [%]		
	2 poles	4 poles	6 poles
0.75	83.5	85.7	82.7
1.1	85.2	87.2	84.5
1.5	86.5	88.2	85.9
2.2	88.0	89.5	87.4
3	89.1	90.4	88.6
4	90.0	91.1	89.5
5.5	90.9	91.9	90.5
7.5	91.7	92.6	91.3
11	92.6	93.3	92.3
15	93.3	93.9	
18.5	93.7		

The paper has the following content: chapter 2 presents the actual efforts to reduce the losses of induction motors; chapter 3 details the design steps and achievements while the conclusions are provided in chapter 4.

2. Methods for Losses Reduction and Performance Optimization for Induction Motors

The induction motors efficiency depends on how big are the total losses that are encountered in the machine as shown in Figure 1, where: P_{IN} – input active power, P_{Cu1} – stator copper losses, P_{Fe} – iron losses, P_{emg} – electromagnetic power, P_{Cu2} – rotor copper losses, P_M - total mechanical power, P_O - output mechanical power, and P_{mec} – mechanical losses.

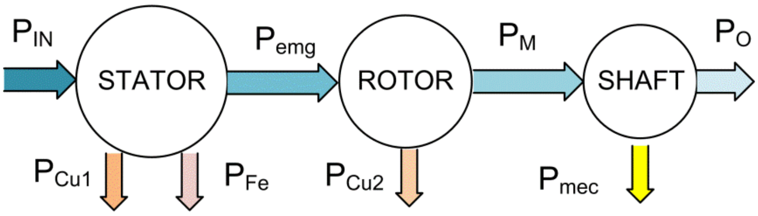

Fig. 1. Induction motor losses diagram

Losses reduction in order to obtain an increased efficiency is done on several directions. One main direction is related to the winding design. It may target the diminishing of the magnetomotive force distortion, with the help of a three-layer winding [5]. Decreasing the voltage harmonics comes as a result of a obtaining a sinusoidal magnetic flux from the air-gap, thus increasing the efficiency by 0.25 % for 0.2 kW motor with one pole pair. On the negative side, this approach required the use of more copper. The use of a multilayer winding such in [6] enabled a 1 % increase in the efficiency of a 0.75 kW motor [6], by decreasing the total copper losses.

The iron losses can be also decreased by the use of steel with higher silicon content, as in [7]. A 0.6% increase in the efficiency was obtained in case of a 15 kW motor. Also on the materials side, a hybrid rotor made from both aluminium and copper in a 40/60 ratio was proposed in [8]. It ensured an increase in both efficiency and starting torque in case of a 7.5 kW motor.

On the induction motors performance side, efforts were made to adjust the inner/outer stator diameter ration for maximizing the output torque. The increase of the stator length will affect only the maximum torque value in case of a 5.5 kW motor operating at 60 Hz [9].

The influence of slot geometric parameters on the average torque, output power an efficiency was investigated in [10] in case of a 60 kW induction motor. The conducted analysis stated that to achieve improvements, both stator and rotor opening heights should be kept as small as possible, while both stator and rotor opening widths shouldn't be that small.

Regarding the estimation of induction motors efficiency, an indirect method that uses the values of the main parameters from the motor nameplate is presented in [11]. Also in this field of interest, Deda & de Kock, [12], have found that actual standards should be put in agreement in terms of computational procedures and estimation of supplementary losses.

3. Design Considerations and Results

This section presents the actions undertaken by the manufacturing company, S.C. Electroprecizia Electrical Motors S.R.L., to optimize their motors for inclusion in the IE4 efficiency class. Motors rated at 1.5 and 3 kW, both having two pole pairs are considered.

One major category of losses is represented by the copper losses corresponding to the stator winding, consisting in main and supplementary ones. As the main copper losses are directly proportional with the resistance of the stator winding, decreasing the value of the latter will have a beneficial impact on the overall efficiency. In this regard, equally displaced coils were used. They are a better solution than concentric coils due to the reducing of the medium length of a winding turn. Moreover, using equal coils ensures the decrease of the head of the coil; this aspect is beneficial because it enables to place in the same motor housing motors with longer magnetic circuits.

The uneven distribution of the current in the cross-section of the conductor is the reason of the supplementary losses from the stator winding. In case of the motors manufactured by S.C. Electroprecizia Electrical Motors S.R.L. Săcele, winding wire is small diameter is used, thus the supplementary losses can be ignored. The main losses from the ferromagnetic core are divided into hysteresis and Eddy currents losses and depend on the specific loss of the steel. In this situation, the stator core was made from M270-50 type steel, having specific losses of 1.1 W/kg. By comparison, the M400-50 steel used for IE3 motors has specific losses of 1.7 W/kg. Thus, for the 1.5 kW motor that has a stator stack mass of 14.826 kg, the use of M270 steel comes, in theory, with 16.35 W losses compared with 25.26 W for the M400 steel. In case of the 3 kW motor, having a stator stack mass of 37.8 kg, the use of M270 steel comes with 41.58 W losses compared with 64.26 W for the M400 steel.

Besides the use of more efficient electromagnetic steel, another method for losses reduction consisted in eliminating the machining process applied to the stator external surface before being pressed to fit into the housing. This is due to the fact that the machining process triggers the short-circuiting of the steel sheets and consequently increases the stator losses. Previous measurements in case of a 7.5 kW motor registered an 8 W losses reduction by not using the machining process [13].

The mechanical losses are divided between ventilation and bearings losses. Ventilation losses reduction was achieved for IE3 motors by the use of cooling fans with smaller diameter. Applied in case of a 15 kW motor with 3000 rpm synchronous speed, it reduced the mechanical losses to 370 from an initial value of 585 W, and also induced noise reduction [13].

Additional or stray load losses have also to be considered when trying to increase an induction motor efficiency. The additional losses are difficult to measure and for sake of simplicity can be considered as 1.8 % from the output power, for motors up to 90 kW, according to [14]. A detailed distribution of these losses is given in Figure 2, according to [15]. From the figure it can be noticed that the largest part is covered by surface losses and the ones generated by the inter-bar currents from the rotor.

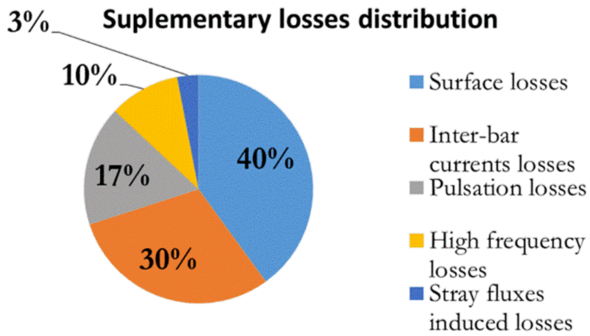

Fig. 2. Supplementary losses distribution

The surface losses are indirect proportional to the surface resistivity, as shown in [13]. Thus, increasing the surface resistivity will lead to losses reduction. On the other hand, the impedance corresponding to the inter-bar currents between neighbouring bars can approximated with the resistance between the bars. Thus, increases the latter one will also lead to losses reduction. One method that succeeds in reducing both surface and inter-bar currents generated losses is the thermal treatment of the rotor cage, also called flaming or thermal shock [15]. In brief, the method consists in the following: putting the rotor in an oven for two hours at 400 °C, cooling it in water up to maxim 30 °C, drying it and painting the core with primer paint to avoid oxidation. It is of importance to mention that the rotor should have the shaft machined, but without the bearings refinished, before the flaming process. Afterwards, the refinishing of the bearings is performed, along with shaft usable end.

To highlight the effect of the thermal treatment on both the efficiency and also on the operating parameters of the motors, tests were performed for two power levels (i.e. 1.5 and 3 kW), with rotors and without thermal treatment. It is worth pointing out that the machining of the rotor surface after the thermal treatment was not performed.

Detailing of the parameters and notations that were used in Table 2 are given below (all motors have a synchronous speed of 1500 rpm):

- M1a - 3 kW, IE4, with untreated rotor;
- M1b – 3 kW, IE4 with thermally treated rotor;
- M2a – 1.5 kW, IE4, with untreated rotor;
- M2b – 1.5 kW, IE4 with thermally treated rotor;
- η – efficiency;
- I_n – nominal current;
- s – slip;
- M_p/M_n – starting to nominal torque ratio.

Table 2. Results

	M1a	M1b	M2a	M2b
η [%]	89.68	90.51	85.79	87.02
s [%]	2.32	2.28	3	2,86
I_n [A]	6.42	6.4	3.71	3.68
M_p/M_n	5.2	4.76	5.83	5.8

More data about the motors: the 1.5 kW motors have a stack length of 140 mm, the 3 kW motors have a stack length of 240 mm; both motors have 36 stator slots and 24 rotor slots. Their main geometrical dimensions are given in Figure 3.

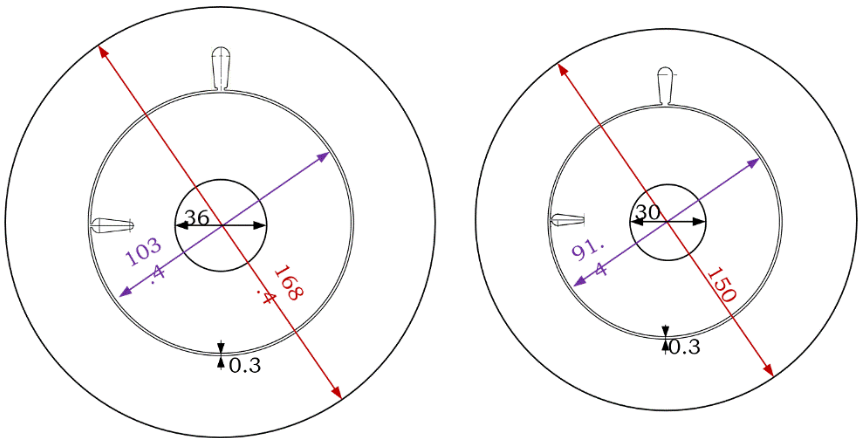

Fig. 3. Cross-section view of the 3 kW motor (left) and of the 1.5 kW motor (right)

For the 3 kW – two pole pairs motor, the standard imposes a nominal IE4 efficiency value of 90.4 %, with a tolerance limit of 88.96 %. For the 1.5 kW – two pole pairs motor, the standard imposes a nominal IE4 efficiency value 88.2 %, with a tolerance limit of 86.43 %.

The results from Table 2 highlight that the flaming process produced the following effects:

- an increase with 1.23 percentage point of the efficiency in case of the 1.5 kW motor – this allows the motor to fall within the IE4 efficiency class;
- an increase with 0.83 percentage point of the efficiency in case of the 3 kW motor (the untreated version was already of IE4 type);
- insignificant variations of the motors nominal currents, slips and maximum/nominal torque ratio.

4. Conclusions

This current work detailed the steps followed by the manufacturing company, S.C. Electroprecizia Electrical Motors S.R.L., to increase the efficiency of the motors that they produce in order to fit within the IE4 efficiency class. The study focused on 1.5 and 3 kW motors with two pole pairs.

The two main optimization directions implied the use of specific steel with lower specific losses and the flaming of the rotor cage. Both methods combined ensured that the manufactured motors achieved super premium efficiency.

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References

1. International Electrotechnical Commission (2014): *IEC 60034-30-1:2014 Rotating electrical machines - Part 30-1: Efficiency classes of line operated AC motors (IE code)*. https://webstore.iec.ch/publication/136
2. Santos V.S., Cabello Eras J.J., Gutierrez A.S., Cabello Ulloa M.J. (2019): *Assessment of the energy efficiency estimation methods on induction motors considering real-time monitoring*. Measurement, ISSN 0263-2241, Vol. 136, pp. 237-247, https://doi.org/10.1016/j.measurement.2018.12.080
3. Verucchi C., Ruschetti C., Benger F. (2015): *Efficiency measurements in induction motors: comparison of standards* IEEE Latin America Transactions, ISSN 1548-0992, Vol. 13, is. 8, pp. 2602-2607, https://doi.org/10.1109/TLA.2015.7332138
4. Esen G.K., Özdemir E. (2017): *A New Field Test Method for Determining Energy Efficiency of Induction Motor*. IEEE Transactions on Instrumentation and Measurement, ISSN 0018-9456, Vol. 66, is. 12, pp. 3170-3179, https://doi.org/10.1109/TIM.2017.2735718
5. Asgharpour-Alamdari H., Alinejad-Beromi Y., Yaghobi H. (2018): *Improvement of induction motor operation using a new winding scheme for reduction of the magnetomotive force distortion*. IET Electric Power Applications, ISSN 1751-8660, Vol. 12, is. 3, pp. 323-331, https://doi.org/10.1049/iet-epa.2017.0381
6. Kabir M.A., Jaffar M.Z.M., Wan Z., Husain I. (2019): *Design, Optimization, and Experimental Evaluation of Multilayer AC Winding for Induction Machine*. IEEE Transactions on Industry Applications, ISSN 0093-9994, Vol. 55, is. 4, pp. 3630-3639, https://doi.org/10.1109/TIA.2019.2910775
7. Lee S., Yun J. (2017): *Influence of electrical steel characteristics on efficiency of industrial induction motors*. Proceeding of 20th International Conference on Electrical Machines and Systems (ICEMS), ISBN 978-1-5386-3246-8, Sydney, NSW, Australia, https://doi.org/10.1109/ICEMS.2017.8056353
8. Kim M.-S., Park J.-H., Lee K.-S., Lee S.-H., Choi J.-Y. (2022): *Performance Characteristics of the Rotor Conductor of an IE4 Class Induction Motor With Varying Al-Cu Ratio*. IEEE Transactions on Magnetics, ISSN 0018-9464, Vol. 58, is. 8, https://doi.org/10.1109/TMAG.2022.3153335
9. Mohamed M.Y., Maksoud S.A.A., Fawzi M., Kalas A.E. (2017): *Effect of Poles, Slots, Phases Number and Stack Length Changes on the Optimal Design of Induction Motor*. Proceeding of Nineteenth International Middle East Power Systems Conference (MEPCON), ISBN 978-1-5386-0990-3, pp. 466-471, Menoufia University, Egypt, https://doi.org/10.1109/MEPCON.2017.8301221
10. Gundogdu T., Zhu Z.-Q., Mipo J.-C., Personnaz S. (2018): *Influence of stator and rotor geometric parameters on rotor bar current waveform and performance of IMs*. The Journal of Engineering, ISSN 2051-3305, Vol. 2019, is. 17, pp. 3649-3654, https://doi.org/10.1049/joe.2018.8244
11. Bortoni E.C., Bernardes Jr. J.V., da Silva P.V.V., Faria V.A.D., Vieira P.A.V. (2019): *Evaluation of manufacturers strategies to obtain high-efficient induction Motors*. Sustainable Energy Technologies and Assessments, ISSN 2213-1388, Vol. 31, pp. 221–227, https://doi.org/10.1016/j.seta.2018.12.022
12. Deda S., de Kock J.A. (2017): *Induction motor efficiency test methods: A comparison of standards*. Proceeding of 2017 International Conference on the Industrial and Commercial Use of Energy (ICUE), ISSN 2166-059X, https://doi.org/10.23919/ICUE.2017.8067991
13. Peter I., Scutaru G., Nistor G. (2014): *Manufacturing of asynchronous motors with squirrel cage rotor, included in the premium efficiency category IE3, at S.C. Electroprecizia Electrical-Motors S.R.L. Sacele*. Proceeding of 2014 International Conference on Optimization of Electrical and Electronic Equipment (OPTIM), ISBN 978-1-4799-5183-3, Brasov, Romania, https://doi.org/10.1109/OPTIM.2014.6850971
14. IEEE Std 112-2017 (Revision of IEEE Std 112-2004): *IEEE Standard Test Procedure for Polyphase Induction Motors and Generators*
15. Nishizawa H., Itomi K., Hibino S., Ishibashi F. (1987): *Study on reliable reduction of stray load losses in three-phase induction motor for mass production*. IEEE Transaction on Energy Conversion, ISSN 0885-8969 Vol. EC-2, is. 3, pp. 489-495, https://doi.org/10.1109/TEC.1987.4765877