

Research on High-efficient Remanufacturing Technologies and Application of Electric Motor

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Abstract. The energy conservation of electric motor system is the key of industrial energy conservation. With the implementation and acceleration of electric motor energy efficiency improvement plan, more and more electric motors are knocked out. High-efficient remanufacturing of electric motor refers to improving the efficiency of electric motor and recycling the resources by replacing the winding, iron core and other components of electric motor on the basis of the low-efficient/outdated electric motors, which conforms to China's policy of circular economy and resource recovery. The remanufacturing of electric motor not only maximizes the use of resources, but also reduces the energy consumption generated by reprocessing of cast iron, silicon steel sheet and other materials in dismantling of electric motor. However, structures and iron core materials used in design and manufacture of electric motors are different, and the degrees of wear of electric motors are also different under different operating conditions, which further result in diversified design schemes, increased remanufacturing cost and reduced remanufacturing efficiency. This paper analyzes the key process technologies for remanufacturing of electric motors are researched by analyzing the remanufacturing technologies of electric motors, and presents the feasibility to replace the cast-aluminum rotor with cast-copper rotor in high-efficient remanufacturing process of electric motor.

1. Introduction

With the highest power consumption, electric motor is used to drive such equipment as draught fans, water pumps, machine tools, mining machinery and hoisting machinery, and is widely applied in various sectors such as mining, metallurgy, chemical, coal, building materials and public utility. According to authoritative statistics, the electric motor inventory in China is about 1.7 billion kW. The total power consumption of electric motors is about 3 trillion kW/h, accounting for about 64% of the total social power consumption ^[1]. In June 2013, the Ministry of Industry and Information Technology of the People's Republic of China and the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China jointly issued the Plan for Improvement of Energy Efficiency of Electric Motor (2013~2015), which specifies the overall objectives for the improvement of energy efficiency of electric motors in China in 2015, and stipulates that totally 160 million kW/h of low-efficient electric motor will be knocked out as of 2015. With the implementation of this plan, the set objectives are achieved, but a mass of abandoned electric motors appear. Therefore, we must consider how to dispose these electric motors. Dismantling of the electric motors may result in resource waste. What's worse, some unscrupulous business persons may recycle and sell the abandoned electric motors



after renovation, which may hinder the implementation of energy efficiency improvement plan. At this time, it is extremely important to develop the remanufacturing of electric motors and accelerate the cooperation with high-efficient electric motor remanufacturers.

2. Policies for electric motor remanufacturing

High-efficient remanufacturing of electric motor refers to remanufacturing the low-efficient electric motors as high-efficient ones or energy-saving motors suitable for specific load and operating conditions (e.g. variable-pole electric motor, variable-frequency electric motors, permanent magnet motors) by means of redesign or replacement of components, and is an effective approach for the cyclic and green development of electric motor manufacturing sector. High-efficient remanufacturing of electric motor may extend the electrical motor manufacturing industrial chain, renovate and optimize the electric motors, change the life cycle of electric motor from manufacturing – use – scrapping – waste recycling to manufacturing – use – scrapping – remanufacturing – reuse – waste recycling, and maximize the potential of electric motor manufacturing sector. With respect to new product manufacturing, remanufactured products can generally save the cost, energy and materials by 50%, 60% and 70% respectively^[2].

In June 2010, the Ministry of Industry and Information Technology of the People's Republic of China prepared *Interim Measures for Accreditation and Management of Remanufactured Product* for the purpose of promoting the orderly and health development of remanufacturing sector, standardizing the production of remanufactured products and guiding the consumption of remanufactured products^[3-6]. Then, *Guidelines for Implementation of Accreditation of Remanufactured Product* was prepared under the organization of the Ministry of Industry and Information Technology of the People's Republic of China according to the *Notice on Printing and Distribution of Interim Measures for Accreditation and Management of Remanufactured Product* (GXBJ [2010] No. 303) to enhance the accreditation and management of remanufactured products, clarify the requirements for accreditation and standardize the accreditation procedures. In 2012, the Ministry of Industry and Information Technology of the People's Republic of China and the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China decided to implement *Plan for Improvement of Energy Efficiency of Electric Motor* for the purpose of implementing energy conservation and emission reduction plans and industrial energy conservation proposed in the Twelfth Five-year Period, accelerating the development, promotion and application of high-efficiency electric motors, promoting the upgrading of electric motor industry and comprehensively improving the energy efficiency level of electric motors^[7-8].

3. Current status and prospects of electric motor remanufacturing market

3.1 Current Status of Electric Motor Remanufacturing Market

The promotion of remanufacturing is not satisfactory and there are slight amount of remanufactured electric motors, although the remanufacturing of electric motors wins great policy support in many countries. According to the investigation and analysis, main reasons are as follows:

a) It is impossible to remanufacture electric motors in batches. Many enterprises refuse to suspend production to remanufacture a batch of electric motors and most of them are unwilling to replace electric motors that can still be used in consideration of normal production. Therefore, it is impossible to remanufacture electric motors in batches due to limited sources and high remanufacturing cost.

b) It is difficult to have the remanufactured electric motors market-oriented due to low degree of recognition of users. Users are more willing to purchase new products, while the remanufactured electric motors are basically directional, i.e. the remanufactured electric motors are finally delivered to enterprises providing them for remanufacturing, so no credible market-oriented remanufacturing is achieved. Users of remanufactured products can be divided as state-owned enterprises and private enterprises. State-owned enterprises tend to purchase new products rather than remanufacture. The choice of private enterprise depends on its economic situation, i.e. it will not remanufacture electric motors if no renovation fund is available, which indicates that the policy promotion and marketing

strengths for high-efficient remanufacturing of electric motor are inadequate. The market can be tapped only after the remanufactured electric motors are recognized and accepted by more users.

c) It is urgent to tackle tax-related issues of remanufactured electric motors. For enterprises, there is no invoice issued for the used electric motors they purchase and only sales invoice for the remanufactured products, so the VAT is extremely high. Therefore, there shall be preferential policies for taxes levied on remanufactured products.

d) There are insufficient standards for remanufacturing of electric motors. Currently, standards for remanufacturing in such sectors as automobile and machinery are relatively complete and mature, while there are insufficient standards for remanufacturing of electric motors. No uniform standards and regulations are provided for the energy efficiency of remanufactured products in terms of recycling and testing of electric motors. There lacks an uniform standard to clarify which electric motor can be remanufactured and which one cannot, considering unlimited types of electric motors to be involved in remanufacturing. It is recognized by experts that it is necessary to remanufacture the electric motors based on their original designs.

3.2 Prospect of Remanufacturing of Electric Motors

The high-efficient remanufacturing of electric motor shall be done based on the design of original electric motor, therefore, it is necessary to ensure that the iron core, groove profile and other structures of the original electrical motor are not changed during remanufacturing. However, the structure and iron core material of the electric motor may be slightly different and the degrees of wear of electric motors may be different at different operation conditions, so there is no uniform design scheme for the remanufacturing of electric motors and different design schemes must be prepared for different electric motors, which significantly reduces the efficiency of remanufacturing and increases the manufacturing cost, making the remanufacturing meaningless. Therefore, it is necessary to maximally refine the design schemes, perfect the development trend of product and maximize the remanufacturing efficiency in process design for remanufacturing of electric motor.

Currently, the high-efficient remanufacturing of electric motor mainly refers to retaining the original rotor core and stator core and replacing new winding, or extending the stator core, equipping with new rotor core and adjusting the winding parameters of the electric motor. At present, there are so many schemes for remanufacturing of permanent-magnet rotor electric motors. However, there are some differences between asynchronous and synchronous electric motors in structure. For asynchronous electric motors, the chutes may raise the cost as the p-m rotor is needed and stator shall be replaced as well, with poor economic efficiency. Cast copper rotor is an ideal choice for energy conservation design of electric motor, but it is still at the exploration stage. During the high-efficient remanufacturing of electric motor, replacing the cast aluminum rotor with cast copper aluminum can effectively improve the efficiency of the original electric motor to IEC efficiency (i.e. Class 2 energy efficiency value indicated in GB 18613) as required by IEC standards in the premise that the starting torque, current and other basic parameters of the original electric motor conform to the standard. With respect to traditional remanufacturing methods, the rotor is easy to be replaced, which can significantly reduce the time for design of electric motor remanufacturing and improve the efficiency. Moreover, the cost of copper rotor only accounts for about 1/3 of the total cost, which is of great significance for cost reduction. Copper rotor is also another choice for the development of remanufacturing technologies. Yunnan Copper Science & Technology Development Co., Ltd., Hebei Electric Motor Co., Ltd., Nanyang Explosion Protection Group Co., Ltd. and many other companies have always been committed to achieving high-efficient remanufacturing scheme for electric motors by replacing with copper rotor, though there are still many problems in production of cast copper rotors for electric motor, including copper smelting (anti-oxidation), pure copper casting process and service life of die.

4. Comparison of electric motor remanufacturing technologies and schemes

Currently, there are mainly three methods for remanufacturing: reducing the capacity of electric motor through remanufacturing and putting into use again; replacing the stator winding; and replacing with

p-m or copper rotor. The electric motor may reach Class 3 efficiency level after it is remanufactured by applying any scheme mentioned above, but it is difficult to reach higher standard if just one scheme is applied. To reach higher standard, it is necessary to renovate the rotor and stator simultaneously, which may significantly raise the cost, so it is infeasible.

In high-efficient remanufacturing of electric motor, corresponding measures will be taken based on the test results of different components. However, as a general rule, the rotor or stator shall be replaced, and engine base (end covers) will be retained; and bearings, fans, fan covers and junction box shall be new and unused (fans and fan covers adopted are of new energy efficiency design).

As for stator, the stator coil solidifies with the stator core as a whole through impregnating insulating paint, so it is difficult to dismantle. In previous experience, the insulating paint is removed by burning the coil, which may damage the iron core and pollute the environment. In remanufacturing, the end of winding is cut with special cutting tool without any damage to the winding and pollution to the environment. After cutting, the hydraulic equipment is adopted to pinch out the stator core which will be then pulled out from the coil after being heated. The coil is then wound as per the new scheme. The wiring and withstand voltage test are then performed after the stator core is cleaned. The qualified stator core will be then put into VPI impregnating vessel for impregnating and then put into the oven for drying. For rotor, intermediate frequency eddy current heater is applied to heat the outer surface of the rotor, separate and protect the spindle and rotor core according to their heat expansion coefficients as there is interference fit between rotor core and spindle. After the spindle is processed, intermediate frequency eddy current heater is applied to pinch in rotor core and new spindle. After the rotor is installed, dynamic balance check is performed in dynamic balancer, and bearing heater is applied to heat the new spindle and install to the rotor. The engine base and end covers shall be reused with the outer surfaces cleaned by sand-blast equipment after there are checked to be qualified. For fans and fan covers, the original components shall be scrapped with high-efficient fans and fan covers applied. For junction box, the cover and wiring board shall be scrapped and replaced with new ones. The base of junction box can be reused after cleaning, and the junction box shall be reassembled. In addition, the electric motor shall be assembled as per the new method for manufacturing of electric motor after the rotor, stator, engine base, end covers, fans, fan covers and junction box are remanufactured with ex-factory test performed.

Table 1. Comparison of remanufacturing Copper Rotor

Scheme	Details	Advantages and Disadvantages	Efficiency after Remanufacturing	Cost of Remanufacturing
S1	Replace fans, bearings, etc.; reduce capacity.	Reach energy conservation standards after reducing the capacity	Class III or lower	10% of cost for new electric motor with equivalent performance
S2	Adjusting the winding of stator	A: reduce copper consumption and electromagnetic noise; D: more complex process, increased man-hour	Over 80% reaches Class III	20% of cost for new electric motor with equivalent performance
S3	Retaining the stator and replacing the rotor with p-m rotor	A: the energy efficiency is increased by 1 class; D: high cost, and to be renovated one by one.	Class III	15% of cost for new electric motor with equivalent performance
S4	Retaining the stator and replacing the rotor with cast-copper rotor	A: the energy efficiency is increased by 1 or more classes; high-efficient renovation; widely applicable; low temperature rise; small volume; light weight; D: high cost.	Class II and Class III	15% of cost for new electric motor with equivalent performance

Cases of Schemes for High-efficient Remanufacturing of Electric Motor

In 2013, the International Copper Association started the high-efficient remanufacturing program that renovating old electric motors with copper rotors together with Yunnan Copper Die-casting Technology Co., Ltd., i.e. replacing the aluminum rotors of existing and old Y and Y2 electric motors with cast copper rotors. In this way, the energy efficiency level of electric motor can be increased by 1 to 2 classes by replacing the rotor system without changing the stator system. It can be applied to change the low-efficient and old electric motors into high-efficient and energy-saving electric motors that conform to the Class 3 or Class 2 energy efficiency requirements specified in GB18613-2012. Meanwhile, it can be used to renovate the brand new Y and Y2 series to launch the Y and Y2 series to be knocked out by improving their efficiency through remanufacturing, which gives chances for manufacturers of Y/Y2 electric motors to manufacture these series of electric motors again. In addition to reducing the energy consumption, the high-efficient remanufacturing technology with cast copper rotor also improves the recycling level of the resources, so it is currently the most cost-effective, simple and feasible scheme for remanufacturing of low-efficient electric motors.

In this paper, the most extensively used and most representative Y132-4 7.5KW and Y160-4 11KW electric motors are adopted for redesign. The electric motors are designed with copper rotors with the stator systems kept unchanged. After the rotor is replaced with the copper rotor, the energy efficiency of the new electric motor is improved from Class 3 to Class 2, by two classes. After remanufacturing, the electric motor with high consumption to be knocked out is renovated as ultra-high-efficient electric motor with remarkable performances.

Table 2. Comparison of Renovation Scheme of 7.5KW-4 Copper Rotor

	Aluminum Rotor	Cooper Rotor Scheme I	Cooper Rotor Scheme II
Efficiency	87.9%	89.18%	88.88%
Power Factor	0.8623	0.8605	0.8534
Locked-rotor Current	6.7	7.49	6.29
Locked-rotor Torque	2.37	2.08	2.27

Table 3. Comparison of Renovation Scheme of 11KW-4 Copper Rotor

	Aluminum Rotor	Cooper Rotor Scheme I	Cooper Rotor Scheme II
Efficiency	90.07%	91.12%	91.25%
Power Factor	0.8497	0.8492	0.8485
Locked-rotor Current	5.99	6.83	7.06
Locked-rotor Torque	2	1.96	2.21

Meanwhile, Y series 0.55-22kW (including 2, 4 and 6-pole) electric motors are selected for full-series renovation. The scheme of redesigning the copper rotor is adopted to improve the efficiency. There are totally 66 types of electric motors in this power range, and all these electric motors reach IE 2 (equivalent to Class 3 in GB18613-2012) after the original rotor is replaced with new-designed copper rotor. Among them, 80.3% (i.e. 53 types) can reach IE 3 (lower than Class 2 in GB18613-2012), with remarkable effect, as shown in the figure below:

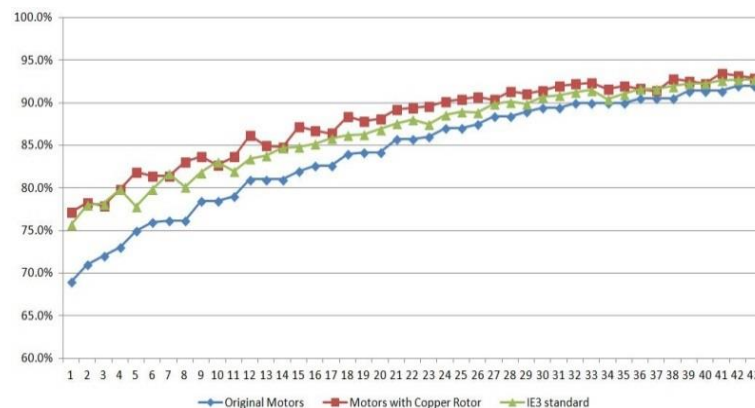


Fig1. Efficiency of different type of electric motors

5. Conclusion

China possesses a large number of industrial electric motors with high energy consumption, which consume 63% of the total social power consumption and 75.1% of the industrial power consumption. Replacing the low-efficient aluminum rotor with new copper rotor to improve the efficiency of electric motor not only saves the energy, reduces the emission, fully recycles waste materials, but also avoids the energy waste due to smelting and processing of old and abandoned electric motors, which conforms to the industrial policy of China featured by conservation and comprehensive application of resources. The cost of replacing with copper rotor is much lower than that of replacing the whole electric motor with high-efficient one, so it significantly reduces the recovery period, effectively promotes the energy conservation of electric motor, and contributes a lot to the industrial energy conservation and emission reduction objectives of China.

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