Research Review of Scrap Metals Eddy Current Separation Technology

1,2 Di WANG, 1 Xiushui MA*, 1 Xiongfei ZHI, 1,2 Shuming ZHANG

1 Ningbo Institute of Technology, Zhejiang University, Ningbo 315100, China
2 Taiyuan University of Science and Technology, Taiyuan 030041, China

* Tel.: 13685891614, fax: 0574-88229505
* E-mail: mxsh63@aliyun.com

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Abstract: The eddy current separation is a technology which applied to the field of resources to be recycled and reused that aimed at separating the scrap metals from the nonmetal substance or separating the metals from different types of scrap metals. This paper introduces the theory of eddy current separation technology, analysis the structure, working principle, advantages and disadvantages of eddy current separation equipment for electrical type eddy current separator (ECS), slipway type eddy current separator and so on. Based on the existing problems and shortcomings, discusses the key technology to resolution in the scrap copper separation field, and makes a brief design of the equipment for separation ferromagnetic metal and nonmagnetic metal at the same time and the equipment of separation for the block scrap copper. Copyright © 2013 IFSA.

Keywords: Eddy current separation, Electrical conductivity, Scrap copper separation, Recycle and reuse, Key technology.

1. Introduction

In 1889, Thomas Edison applied for the patent of alternating magnetic field eddy current separator which was used in separation of nonferrous metal and nonmetal. However, due to the electromagnetic alternating magnetic field eddy current separator structure is heavy, large investment, low separation effect and so on, this separator failed to be widely used in the non ferromagnetic metals recycle and reuse industry. With the development of permanent magnetic material, barium/strontium ferrite magnet (1957), samarium cobalt magnet (1974) and NdFeB magnet (1984) have been invented and put into industrial production. The separation principle research and equipment research and development of the permanent magnet eddy current separator appeared successively. In the late 80s to early 90s of twentieth century, Germany and the United States had developed successfully Nd-Fe-B permanent magnet roll eddy current separator (PMRECS) [1].

Eddy current separation is a kind of effective method of recycling non-ferrous metals from industrial waste and city garbage [2], which has many advantages, such as good separation effect, strong adaptability, reliable mechanical structure, light weight, strong repulsive force (adjustable), high separation efficiency, high yield and so on. Its main processing objects are copper (aluminum) power cable, aluminum products, automobile waste, non-ferrous metal chips, printed circuit board ash, non-ferrous metals glass fragments, electronic product
waste, multi-metal (Al, Cu, Pb, Zn) mixture, cast copper (aluminum) foundry sand, aluminum dross and so on. Its application areas are: (1) the city solid waste materials disposal; (2) the industrial solid waste materials treatment; (3) the foundry sand refinement in aluminum, copper and other non-ferrous metal casting industry; (4) the resource processing of electronic waste [3, 4].

At present, the famous eddy current separator manufacturers in the world have: United States Eriez Magnetic company, Germany Wagner company and Steinert company, Spain Unelco company and Indonesia Paicon company. Among them, the United States Eriez Magnetic company is one of the largest manufacturers of eddy current separator in the world. The eddy current separation technology development in China is relatively late, the existing of eddy current separator manufacturers in China have: Hangzhou Keqiao MagnetoElectric Equipment Co., Ltd., Suzhou Ployma Environmental Protection Equipment Co., Ltd., Shanghai Fumeng Mechanical and Electrical Technology Co., Ltd., Henan Sanxing Machinery Co., Ltd., Fushun City Jinshe-Yuyi Mechanical and Electrical Equipment Manufacturing Co., Ltd., Shandong Huate Magnet-electronic Technology Co., Ltd., and so on. With the development of technology, the eddy current separator performance of these company produces is improved, but there is a larger gap in the separation efficiency, control technology and intellectual property rights, etc., compared with the world advanced level. To speed up the development of China eddy current separation technology and reduce the gap with the world advanced level, this paper reviews international and domestic status of the eddy current separation technology, analyses the existing problems and deficiency, expounds the development trend of the technology.

**Principle of Eddy Current Separation Technology**

The principle of eddy current separation technology is based on two important physical phenomenons: the Faraday's law of electromagnetic induction and the alternating magnetic field and the induced magnetic field interact to produce repulsive force [5-7].

The principle schematic diagram of the eddy current separation technology is shown in Fig. 1. When with the electric conductive non-ferromagnetic metal passes through the alternating magnetic field, the eddy current will be produced in the metal conductor. The eddy current induces magnetic field and its direction is contrary to the alternating magnetic field direction, the induced magnetic field interacts with alternating magnetic field and produces repulsive force on the metal. Through the analysis of the repulsive force, we can get the repulsive force \( F_r \) is:

\[
F_r \propto \frac{H^2 f \sigma}{s},
\]

where \( H \) is the magnetic field intensity, \( f \) is the frequency of alternating magnetic field, \( \sigma \) is the volume of metal, \( \sigma \) is the electrical conductivity of metals, \( s \) is the shape factor of metal [8].

In formula (1), supposing the magnetic field intensity, the frequency of alternating magnetic field, the volume of the metal and the shape factor of the metal are constant, the magnitude of the repulsive force \( F_r \) is only related to the electrical conductivity of the metal. The repulsive forces that metal of different electrical conductivity produced are different. Therefore, metal materials of different compositions can be separated from the mixed metal material under different repulsion forces, so as to achieve the aim of separation.

**Fig. 1. Principle diagram of eddy current separation technology.**

3. Domestic and Foreign Research Status and Existing Problems

3.1. Domestic and Foreign Research Status

At present, the domestic and foreign research and application of eddy current separation technology and equipment have the following categories.

1) “Electrical type” ECS.

This equipment adopts the traveling wave magnetic field which is produced by polyphase AC electromagnet. The “electrical type” eddy current separator structure is shown in Fig. 2, its structure mainly include follow four parts: the linear motor stator perpendicular fixed to the conveyor belt, conveyor belt, roller and collection hopper [9]. Its basic working principle is when the alternating current flows through the coil which is installed on the conveyor belt above and below, the traveling wave magnetic field produced by the inductor moves from the central to two sides of the conveyor belt.
When the waste material containing non-magnetizer metal (such as lead, aluminum, zinc, etc.) passes through the alternating magnetic field with a certain speed, the non-magnetizer metal internal can produce induced eddy current. Because there is a relative motion between the waste material and the magnetic field, the repulsive force on the eddy current metal sheet (or block) is produced. The magnitude of repulsive force varies with the properties of the waste materials electronic conductivity and permeability and the change rate and value of magnetic flux density. Using of this principle, we can separate some non-ferrous metals from the mixed waste material. This equipment has features of operation simple, low power consumption, etc. But this kind of separation equipment is only suitable for dealing with coarse grain materials and the recover belt moving speed should not be too fast and only suitable for small batch processing.

2) “Slipway type” ECS.

The structure of “slipway type” eddy current separator is shown in Fig. 3, using drum type alternating magnetic field, the mainly structure is feeding inclined plate, permanent magnetic drum driven by a motor and collecting hopper [10]. Its basic working principle is the waste materials were sent to the feeding inclined plate and downslide along the surface of chute, the magnetic flux pass through the conductor particles is changing, so eddy current produced in the conductor particles, under the contribution from Lorentz force, gravity, centrifugal force, mechanical force, the movement orbits of conductor particles is shift, because of different conductor particles its the conductivity is different, and electromagnetic force is also different, so all kind of conductors particles were separated into different collecting hopper. However, the slipway of this equipment is inclined and fixed, but the waste materials feeding speed can not regulation, conductor particles are easily collide each other, splash and scattered when waste materials feeding so much that the interaction force of each other is larger than Lorentz force lead to loss the separation action, so this separator is not suitable for the requirements of large quantities separations processing.

3) “Vertical spinning drum type” ECS.

The “vertical spinning drum type” eddy current separator (VDECS) structure is shown in Fig. 4, in Fig. 4, “1” is vertical spinning drum, which is embedded with NdFeB permanent magnets, permanent magnets is alternating arrangement by N–S and S–N, its structure is shown in Fig. 5. The vertical spinning drum is directly fixed on the axis “7” of the motor “2”. The motor “2” power supply is by power “4”. The vertical spinning drum and the motor are covered with a cylindrical plastic shield “6”. The waste material to be separated is brought from feeder “5” through feeding inclined palate “3”. The feeding inclined palate is inclined with the angle $\alpha$ respect to the horizontal plane. The distance between lower end of feeding inclined palate and shield “6” is $d$.

When the waste materials (scrap metal and non-metal) fall into the magnetic field that along with the feeding inclined palate. The waste materials hit the plastic surface which surrounds the vertical spinning drum, thus produce centrifugal motion. The non metal particles are reflected and fell. The metallic particles are affected by the deflection force caused by the collision, and the magnetic field force interaction which is produced by the eddy currents induced magnetic field and the permanent magnet field. The received force of metal particles is larger than the non metal particles. Consequently, non metal particles are fall at a larger distance relative to the metal particles [11]. In order to improve the efficiency of separation, the rotation speed of drum can not be too high and must choose proper parameters. The advantages of the VDECS are reduce the separating equipment investment and able to separate millimeter level non-ferrous particles, but there is a certain distance between feeding inclined palate and plastic shield, it is easy jam when the size of some waste materials is too big, while the size of some waste materials is small, it can not full interaction with the magnetic drum, so the separating efficiency is low. Many factors influence the structure design, based on experiment research
analyze, the product of the first separation must be reprocessed again by eddy current separation thus increase the cost of separation.

4) “Roll type permanent magnetic” ECS
The magnetic roller of “roll type permanent magnetic” ECS have two types, they are concentric winding (see Fig. 6) and eccentric winding (see Fig. 7) [12, 13]. Concentric winding magnetic roller is fixed and can not be adjusted, but the magnet pole position of eccentric winding magnetic roller can be adjusted based on the different materials, so as to the non-ferrous particles can jump off in the most suitable angle and obtain the best separation result. The structure of “roll type permanent magnetic” ECS is shown in Fig. 8, it include magnetic separator, feeder, feed belt, multipole magnets drum and collecting hopper.

The principle of “roll type permanent magnetic” ECS is similar to “slipway type” ECS, but the separation property is better than “slipway type” ECS, so it is one of the most widely used ECS at present. Because of the feed rate, rotational frequency of the feed belt and alternating magnetic frequency can be adjusted in a certain range, the separating efficiency of ECS is closely relate to the magnetic field intensity, the rotational speed of separating cylinder, the speed of feeding and the size of waste materials [14]. Therefore, the separating capacity of this equipment is large and separating efficiency is high. The best significant feature of this equipment is that it can magnetic separation, ferromagnetic materials were wiped off before eddy current separation, which separating equipments mentioned before do not have, therefore, it can avoid the damage to feed belt because of the thermal effects of ferromagnetic materials during eddy current separation operating. However, the structure of this ECS is complex and the separating efficiency of magnetic separator is low, the feed belt is still can be damaged because of some ferromagnetic materials left and shorten feed belt life.

5) “Static type” ECS.
The side section view of “static type” ECS is shown in Fig. 9, this equipment consists of six-part: feeder with the metallic and nonmetallic particles, slanting surface, flat rectangular coil, vibrator, rolls and collection hopper. Flat rectangular coil is inserted in the middle of the slanting surface in a vertical way, the slanting surface has double inclination, one is a certain angle relative to level, so as to the particles can fall down because of their weight, the other
inclination respect to the surface of the coil is shown in Fig. 10, the vertically insert flat rectangular coil divided the slanting surface into two halves, the acute angle which each half of slanting surface makes with the flat rectangular coil does not allow material falling from two side [15]. The basic working principle is a very intense variable magnetic field produced during flat rectangular coil charged with high frequency alternating current, when metallic and nonmetallic particles tumbled onto the area of the high frequency flat rectangular coil, the force of electromagnetic will throw the metallic particles of the slanting surface into the metallic collection hopper and the nonmetallic particles will fall at the end of the slanting surface into the collection hopper.

This equipment use high frequency flat rectangular coil instead of permanent magnetic drum, not only remove some big power facilities compared with “roll type permanent magnetic” ECS, such as motor, conveyor belt and so on, but also can achieve magnetic separation and more efficient. In addition, by adjusting the angle between slanting surface and ground, material’s down slip velocity can be controlled, so this equipment realize the electric function from the perspective of mechanical. However, this equipment is only appropriate for separating metals from nonmetal, it is impossible to realize the separation among different metals. Therefore, its application was limited and unable to meet the needs of nonferrous metals resources of recycling industry in China.

3.2 Problems and Deficiencies

In conclusion, there are some problems and deficiencies when using eddy current separation technology.

1) Existing eddy current separation equipments have some problems such as low efficiency and low effect of separation etc. After separating by some equipment, workers have to separate the scrap metals twice. The main reason of this phenomenon is the absurdity of the constructive design and the relevant parameters of separation system, such as feeding speed, belt speed and rotating speed of drum. This problem needs to be solved in the further research.

2) The application of the existing eddy current separation technology can be used in operating metal and nonmetal, the separation of different brands of the same type of metal (such as different brands of copper) is not very maturity.

3) Eddy current separation technology can separate the fragile scrap metals, while there are some large scrap metals (such as radiator) not crush easily. So how to separate these scrap metals, there are no related researches or applications nowadays.

4) Existing eddy current separation equipments cannot separate ferromagnetic materials. Before eddy current separation, ferromagnetic materials must be wiped off by magnetic separation equipments. This phenomenon wastes both time and labors, it also increase the costs of the device.

4. Trends of Eddy Current Separation Technology

Although our country has a certain level of developing of the eddy current separation technology, there are some performances in scrap metals’ recovery and recycling. While the research depth is not inadequate, the level is not high, and the range of applications should be expanded. Besides, to the increasing shortage of copper resources, using scrap copper smelting copper is inevitable. How to achieve the precise separation and make full use of the scrap copper becomes a hot and difficult issue to relief the lack of copper mineral resources. How to make the eddy current separation technology apply to scrap copper separation is the main direction of this technological development. Therefore, scrap copper separation which based on eddy current separation technology should be solved follow below.

1) The study of automation device can finely divide the broken scrap copper. When the device processes the broken scrap copper, different components and qualities of scrap copper can be automatic separation because of different categories.

2) The design and research of the efficient magnetic separation device. In order to solve the technical problem, ferromagnetic metal cannot be separated simultaneously. The top view of scrap
copper eddy current separator is shown in Fig. 11. When ferromagnetic metal impurities in scrap copper materials been sent to the conveyor belt by vibrating feeder, the scrap copper should be across the magnetic separation device first, then the device will adsorb the ferromagnetic materials from the waste materials, the back and forth movement of the brush will sweep down the adsorbed ferromagnetic material to the two sides of the collecting hopper, finally the rest of the scrap copper will enter the eddy current separation process.

![Fig. 11. Structure diagram of ECS equipment.](image)

3) Blocks of scrap copper (such as automobile radiator etc.) separation technology research. Eddy current sensor has different equivalent impedances when detects different qualities of copper (different conductivities), this principle can be used to detect, distinguish and separate large lumps of scrap copper. The schematic diagram of component measurement and separation system is showing in Fig. 12. When blocks of scrap copper are carried on conveyor belt by feeding device, the signal is measured and sent to the control system, then the single chip microcomputer can process, analyze and judge the data and determine the category of scrap copper. The result will display on liquid crystal display (LCD) after a certain delay. At the same time, through executive device (the pushing cylinder) to promote the appropriate level of scrap copper from the corresponding channel into the aggregate boxes.

![Fig. 12. Schematic diagram of component measurement and separation system.](image)

5. Conclusion

Although eddy current separation technology is widely used in metal and nonmetal separation area, mineral separation area and scrap metal separation area. There also exist problems in scrap copper smelting area and other engineering application fields, such as low separating efficiency and precision. Therefore, based on the existing technology, it is imperative to carry out theoretical and applied researches.

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