Review of Permanent Magnet Lifting Technology

Ning Ding 1*, Shanfu Cui1, Chao Liu1, Jingsong Duan1, Shuna Jiang1
1Vehicle and Mechanical Engineering Institute, Changchun University, Jilin, China
*dingn@ccu.edu.cn
1437189572@qq.com, cuishan666@163.com, 915946648@qq.com, 1970650355@qq.com

Abstract — Permanent magnet lifting technology refers to the knowledge of the process of magnetic material suction unloading and transfer through permanent magnet lifting device with strong magnetic material as magnetic field energy. Compared with the traditional electromagnetic lifting device, the permanent magnet lifting device attracts and lifts ferromagnetic objects through the magnetic force of strong magnetic permanent magnet materials without excitation current during the lifting operation. Therefore, the permanent magnet lifting device has the advantages of energy saving, reliable use, low cost and high weight absorption ratio. This paper introduces the development of permanent magnet lifting technology, including the working principle and design problems of permanent magnet lifting device. According to the different demagnetization methods, it can be divided into electromagnetic demagnetization type lifting permanent magnets and mechanical demagnetization type lifting permanent magnets. Finally, the prospect of permanent magnet lifting technology is prospected and suggestions for its development are put forward.

1. Introduction
With the continuous development of contemporary China's productivity, the energy industry in various manufacturing industries in various regions of the supply imbalance and insufficient contradictions are increasingly intense. In order to improve the energy efficiency, optimize the energy structure, implement and strengthen the implementation of environmental protection, and put the sustainable development strategy into practice, it is imperative to develop green and low-carbon industries to save energy. In the traditional metallurgical steel rolling, port lifting and other industries need to lift ferromagnetic lifting equipment, lifting electromagnet is one of the main parts of lifting. The lifting electromagnet has many advantages such as mature technology, wide application and high efficiency, but it has the disadvantages such as large power consumption, poor safety, short service life and inconvenient maintenance. In the 1960s, the University of Southampton in France proposed the idea of developing permanent magnet lifting equipment. Subsequently, a small tonnage permanent magnet lifting equipment appeared in Milan, Italy. In 1978 Kruppe developed an electromagnetically controlled permanent magnet crane[1].

At the same time, the emergence of rare earth permanent magnetic materials in the late 20th century greatly promoted the progress of related industries. Rare earth permanent magnetic materials have excellent properties such as low density and good mechanical properties. The development of rare earth permanent magnet has gone through three stages: the first generation of unroofed cobalt, the second generation of unroofed cobalt, and the third generation of NdFeb. In addition, China is the largest rare earth resource country in the world, with 23% of the rare earth resources providing over 90% of the
world's market supply. However, most of the rare earth resources are exported as raw materials, so it is urgent to develop rare earth industrial products instead of exports.

Therefore, the technology of permanent magnet lifting which uses strong magnetic materials as the magnetic source to complete the lifting work of ferromagnetic devices can be better developed. Compared with traditional electromagnetic lifting, permanent magnet lifting technology shows that:

1. Save energy. This is the most prominent advantage of permanent magnet lifting technology, through the transformation of magnetic circuit to achieve the suction of goods unloading, lifting action without power, great energy saving.

2. Stable performance, reliable and safe. The working process of traditional electromagnet has the hidden danger of safety accident caused by loss of suction due to power failure. The permanent magnet material of permanent magnet lifting device has high magnetic energy product and great force, which can reduce the influence of load fluctuation on lifting performance.

3. Simple structure, uniform suction. Permanent magnet lifting device does not need the complicated equipment of electromagnetic lifting, its structure is simple and clear, convenient for fault detection and maintenance. Moreover, the reasonable arrangement of permanent magnets can make the magnetic field lines on the working surface of permanent magnet crane more evenly distributed than those on the traditional electromagnetic lifting surface, and reduce the difference of suction at each point.

4. High suction ratio. The magnetic source of lifting permanent magnets is mostly rare earth permanent magnet materials with high magnetic energy and strong coerc. Especially with the preparation technology and magnetic properties of Nd-Fe-B permanent magnet becoming more and more perfect, Nd-Fe-B permanent magnet is more and more widely used in this magnetic machinery, which highlights the advantages of small size and high weight-absorption ratio of rare earth lifting permanent magnet.

2. Working principle of permanent magnet lifting device

The permanent magnet lifting device takes the strong magnetic material as the magnetic source, and there is no need to electrify when lifting. The lifting ferromagnetic object is placed within the scope of magnetic force, and it can be absorbed on the working magnetic pole by relying on the permanent magnet material to produce a certain magnetic force. The design ideas of unloading can be roughly divided into two categories: the first is to reduce the magnetic field on the working magnetic pole by means of an electrified excitation coil until the magnetic attraction is reduced to a certain extent to realize the unloading of objects. The second type is based on the continuity principle of magnetic flux and superposition principle of magnetic field, through the relevant structure and magnetic circuit design of lifting permanent magnet, reducing magnetic suction to complete the unloading. Therefore, according to the difference of unloading principle, permanent magnet lifting devices can be divided into two categories: electromagnetic demagnetization permanent magnet lifting and mechanical unloading permanent magnet lifting[2].

2.1 The principle of electromagnetic demagnetization

In the suction state of the permanent magnet lifting device, the magnetic field line starts from the N pole of the internal permanent magnet, passes through the yoke, then passes through the ferromagnetic workpiece back to the yoke, and finally enters the magnet S pole. When unloading is needed, a certain number of excitation coils wrapped around the permanent magnet body can be powered on to generate a reverse magnetic field to offset the permanent magnet field, and the unloading can be realized when the magnetic attraction is weakened to a certain extent.

2.2 Working principle of mechanical unloading type

Generally speaking, the lifting permanent magnets of the mechanical unloading type complete the unloading of permanent magnets by changing the path that the magnetic field line passes through, namely the magnetic circuit, gradually reducing the magnetic field line in the ferromagnetic absorbent or making the magnetic field line not pass through the magnet at all but by lifting permanent magnet yoke to
complete the self-closing of the magnetic circuit. The different unloading methods can be divided into forced unloading and magnetic self-closed type.

3. Examples of permanent magnet lifting devices

3.1 Electromagnetic demagnetization type permanent magnet lifting

Electric pulse charging demagnetization type permanent magnet lifting

The electromagnetic pulse demagnetization developed by Huang Yanliang and Huang Zeliang[3] is a permanent magnet lifting device. Its structure consists of a permanent magnet, a pole head and a conjugate body. The pole head is fixed at the bottom of the permanent magnet; The conjugate body is coated with the permanent magnet, pole head and coil. The basic principle is as follows: when the coil passes with a certain direct current pulse current, the permanent magnet is saturated and magnetized. At this time, the magnet is in a suction state and the lifting load is strengthened. The permanent magnet is demagnetized when the coil passes with a certain reverse dc pulse current, and the permanent magnet is discharged. The magnetic source of this kind of lifting permanent magnet is required to be easy to magnetize and demagnetize and have strong remanence state. Therefore, permanent magnet materials with low coerc and high remanence are selected. For example, alNi-Co5 permanent magnetic alloy or Fe-Cr-Co permanent magnetic alloy, however, the maximum magnetic energy product of such permanent magnetic materials is small, which cannot achieve ideal lifting effect.

Magnetic switch type permanent magnet lifting

Huang Yanliang and Huang Zeliang[4] developed permanent magnet lifting sucker, which is a kind of magnetic switch type permanent magnet lifting device. The design idea of the device is: the main magnetic circuit composed of ndfeb with strong magnetic material and the secondary magnetic circuit composed of ferrochromium and cobalt with small residual magnetic force as the coupling system. The main magnetic circuit assumes the main body of the magnetic circuit and the secondary magnetic circuit realizes the opening and closing of the magnetic circuit.

Electromagnetic inverse magnetic field cancellation formula

The hoisting permanent magnet developed by Huang Yanliang and Huang Zeliang[5] as shown has both permanent magnet and electromagnetic magnetic circuit. The structure of the permanent magnet lifting equipment is a magnetic yoke shell. There are several receiving cavities in the yoke shell. A permanent magnet and a coil on the top of the permanent magnet are arranged in each receiving cavity.

When the device is sucking, the lifting is completed through the magnetic suction of the permanent magnetic circuit. When the device is unloading, the electromagnetic magnetic circuit produces a reverse magnetic field to offset the magnetic field of the permanent magnetic circuit, thus reducing the magnetic suction to realize unloading.

3.2 Mechanical unloading type permanent magnet lifting

3.2.1 Forced permanent magnet lifting

Multi-boom type permanent magnet lifting

Huang Weiliang[6], developed plunger type lifting permanent magnets is using purely mechanical structure a new type of permanent magnets, unloading heavy on its basic principle is through the boom and jib under limit device in lifting heavy unloaded between open and close the plunger can be unloaded when would pull into pressure during lifting, thus starts a, isolate artifacts in the effective magnetic absorption area to achieve discharge.

The device is mainly composed of roof, permanent magnet block, ejector rod, lifting support, driving arm, limit pin and lifting plate[7]. The lifting support is connected on the roof. The lifting support is connected with the lower rotating arm; The end of the lower rotating arm is equipped with the ejector bar, the other end is connected with the upper rotating arm, and the upper rotating arm is connected with the
lifting plate. The limit hole at the lower end of the lifting plate is matched with the limit pin on the roof. FIG. 1 shows that when the weight is absorbed, the lifting plate and the roof lock the limit through the limit pin, so the upper and lower tumblers will not rotate. When unloading, the limit pin is opened. During lifting, the lifting plate rises and drives the tumbler to rotate, while the lower tumbler drives the ejector to press down, so that the roof is separated from the workpiece, and the unloading is realized, as shown in Figure 2.

Fig. 1. Multi-arm jackhammer type permanent magnet for lifting weight

Fig. 2. Multi-arm jackhammer type permanent lifting magnet for unloading

Double arm pole lifting permanent magnet crane

The lifting and unloading process of the multi-boom type permanent magnet crane requires manual operation of the positioning between the lifting plate and the roof, so as to achieve normal loading and unloading work, which limits the use scenarios of such equipment. Therefore, in some special working conditions, the improved double arm ejector permanent magnet is more suitable. The double arm pole lifting permanent magnet structure developed by Huang Weiliang and Liu Jianhua [8] includes ratchet wheel, pawl, CAM, tumbler, baffle, pole jacking, spindle and lifting support. There are lifting supports at both ends of the roof; The main shaft is provided on the lifting support; The main shaft is equipped with ratchet wheel, CAM and rotary arm; Below the CAM lies the jacking rod. The hook drives the rotary arm upward, and the pawl movement in the same direction with the rotary arm drives the ratchet wheel to rotate at the same time. At the same time, the CAM and the ratchet wheel are connected by the coaxial key. Therefore, the CAM rotates at a certain angle. When the workpiece is hoisted to the specified position and the magnetic lifting is completed, the movable pawl of the tumbler slides to the next tooth of the ratchet, and then the hook rises. The rotation of the tumbler drives a series of components to move. Finally, the CAM bump is in contact with the jacking rod to press it down and push the workpiece out of the magnetic suction area.

Fig. 3. Double arm ejector permanent magnet lifting weight
3.2.2 Magnetic circuit self-closed type permanent magnet lifting

**Translational displacement type permanent magnet lifting**

The magnetic system of translational displacement lifting permanent magnet is divided into upper magnetic system and lower magnetic system, among which the element magnetic blocks are interwoven with a yoke. According to the continuity of magnetic flux and superposition principle of magnetic field, the superposition and offset of magnetic field are completed by horizontal translation of upper and lower magnetic system\[9\]. According to the above principle, the corresponding driving device is developed to realize the horizontal movement of the upper and lower magnetic system. In the same way, Guan Bingsan, Han Zhongfan and Wang Ying [10] developed the design of translational guide rail in two magnetic systems, and completed the offset and superposition of magnetic field through the transmission of motor, gear, rack and other devices. Compared with the former two methods, the new lifting permanent magnet developed by Fang Wei and Fang Zhihui does not use a motor in its design, but USES a CAM lock box mechanism to convert the vertical movement during lifting into the horizontal displacement movement between the two magnetic systems. The device includes lock box, CAM, traction cable and lifting sling. The lock box is set in the middle of the magnetic system. The rotation of the CAM in the lock box can be transformed into the left and right movement of the magnetic system. The ratchet wheel rotates before the CAM when the CAM rotates. When the CAM drives the left magnetic pole shift, each magnetic pole plate of the upper magnetic system is aligned with the plate of the two lower magnetic system, the magnetic field line is directly through the upper plate of the lower plate to make the circuit short, showing the unloading state. This completes a cycle of work.

**Rotating displacement type permanent magnet lifting**

The stacking and canceling of magnetic field is completed by the flip of magnetic pole. At present, the rotary displacement type crane permanent magnet is generally designed with reliable and stable mechanical structure. According to the difference of mechanical structure, it can be divided into handle type crane permanent magnet, ratchet wheel drive crane permanent magnet, gear drive crane permanent magnet, sprocket drive crane permanent magnet four categories.

3.2.2.1 Ratchet driven permanent magnet crane

Ratchet driven permanent magnet lifting device is a lifting permanent magnet which can reverse magnetic pole and realize the function of magnetic field superposition and offset by ratchet wheel mechanism. Wang Minxian, Ding Ning[11] and other successful design of the rotary lifting permanent magnet automatic suction and unloading device through the ratchet wheel, pawl, swing rod and other components of the transmission mechanism, the upward traction of the crane into the torque of the rotating magnetic system shaft. When the device is in the state of weight absorption, the pendulum rod is horizontal as shown in FIG. 5. When the rotating magnetic system is horizontal in the polar direction, the magnetic field line is short connected by the internal and external magnetic body. When lifting, the chain drives the swing rod on the rotating shaft to rotate. When the swing rod is upright, the rotating magnetic system

---

**Fig. 4.** Double arm pole lifting permanent magnet for unloading
rotates by 90°, and one end of the magnetic pole is downward. At this time, the device shows suction, as shown in Figure 6. When unloading, as the hook falls, the position becomes horizontal under the action of the pendulum rod's own gravity, and the pawl slides against the ratchet to the next tooth under the action of the return spring at the same time. When the hook is pulled again, the pendulum rod repeats the previous rotation action, and the ratchet is driven by the ratchet to make the rotating magnetic system turn 90° again. At this time, the permanent magnet is short-circuited by the internal and external magnetic body to realize unloading. Repeat the above actions to complete the process of suction and unloading the ferromagnetic workpiece.

3.2.2.2 Gear driven permanent magnet lifting
The working principle of gear driven crane permanent magnet is basically the same as that of ratchet wheel driven crane permanent magnet: the rotating magnetic system is turned over by gear mechanism. Gao Changcheng, Ding Ning[12-19]and other design of lifting permanent magnets adopt gear structure to drive the magnetic system rotation. Its working process: when the crane is lifting, the upper pull of the hanging beam drives the swing rod to rotate counterclockwise; the pawl motion connected with the swing rod drives the ratchet; the large gear coaxial with the ratchet wheel drives the meshing pinion to rotate; finally, the rotating magnetic system is rotated 90°; at this time, the magnetic pole direction of the permanent magnet is downward to realize weight absorption, as shown in Figure 7. When fall hook, swinging rod under the action of gravity swing clockwise to the horizontal position, ratchet in a reset spring under the action of clingy ratchet wheel sliding to the next, ratchet wheel, gear structure did not move, when the hook rises, the motion of the pendulum rod drives the ratchet drive ratchet wheel rotation, through the gear mesh make turn 90° rotating magnetic system, the level of permanent magnet poles, the external performance for unloading heavy, as shown in figure 8.
4. Urgent problems to be solved

4.1 Unit permanent magnet assembly and magnetic circuit problem
At present, it is difficult to make permanent magnets of bulk rare earth materials by casting, powder metallurgy and subsequent heat treatment. At present, it is difficult to realize the use of a small number of large permanent magnet system prepared by the transport of large steel lifting equipment. In addition, the size of permanent magnet also limits the size of permanent magnetic circuit. In order to reduce magnetic flux leakage, the magnetic circuit should be compact. How to combine as many units as possible to obtain the most ideal magnetic circuit effect is the key research object.

4.2 The problem of multi-field interaction in magnetic circuit
The interaction between multiple unit permanent magnets in magnetic circuits still lacks a clear and definite theory. The importance of unloading in permanent magnet lifting is more complicated than that of weight absorption. In order to meet the design requirements, the magnetic induction intensity on the working pole surface of permanent magnet lifting lifting lifting lifting should be limited in a certain range. Understanding the interactions between magnetic fields may be a big step forward in permanent magnet lifting technology.

5. Summary
Magnetic self-closing permanent magnet lifting has become the development trend of permanent magnet lifting technology by virtue of its advantages in unloading. Compared with traditional electromagnetic lifting, permanent magnet lifting technology has a unique advantage and a bright future, but there are still some key problems to be solved satisfactorily. Permanent magnet lifting technology has a wide application prospect and huge potential. However, there is still a lot of work to be done in the design of suction and discharge device, interaction rules between multiple magnetic fields, and optimal design of magnetic circuit, etc., and there is still a long way to go in the exploration of permanent magnet lifting technology.

Acknowledgement
The research project was supported by Industrial Technology and Development Plan of Jilin Province (2018C043-2), and Science and Technology Development Plan of Jilin Province (20200401111GX).
References

[1] Lin Qi-ren, Zhao You-min. Design principle of magnetic road [M]. Beijing: Machinery Industry Press, 1987.

[2] Liu Chao, DING Ning, DUan Jingsong, JIANG Shu-na. Research Status and Prospect of Crane Permanent Magnets [J]. Hoisting Transport Machinery, 2019(14): 68-75.

[3] Song Houding et al., permanent magnet materials and their applications, Beijing: Machinery Industry Press, 1984.

[4] Qi Fengchun, Wu Weimin. Chinese patent No 92225510.5

[5] Xia Wei, Cao Yunlong et al. Chinese patent No 89221795.9

[6] Huang Weiliang, LIU Jianhua. Multi-arm Jackhammer Permanent magnet [P]. Chinese Patent : 20130248610.4, 2013-10-30.

[7] Huang Weiliang, LIU Jianhua. Lifting Permanent magnet for Movable Magnetic plate [P]. Chinese Patent: 201310169057.X, 2013-08-07.

[8] Huang Weiliang, LIU Jianhua. Double arm Lifting Permanent magnet [P]. Chinese Patent: 201320248609.1, 2013-10-30.

[9] Ding Li-Gong, Yang Shu-Qing. Translational Rare earth Permanent Magnet Crane [P]. Chinese Patent: 89209146.0, 1990-06-27.

[10] Guan Ping-san, HAN Zhongfan, WANG Ying. Translational rare earth Permanent magnet Crane [P]. Chinese Patent: 91209735.3, 1993-03-17.

[11] Gao Changcheng, Ding Ning, Wang Minxian, et al. A device for automatic suction and discharge of suction with rotating permanent magnet for crane [P]. Chinese patent: 92245257.1, 1994/04.27.

[12] Ding ning, Zhang ding-tong, Pei yi-zheng. Novel and Energy-saving Lifting Permanent Magnet Design[J]. Advanced Materials Research, 2011: 2846-2849.

[13] Ding ning, Zhang ding-tong. Intelligent Optimization Design of Rare Earth Lifting Permanent Magnet [J]. Advanced Materials Research, 2012: 3066-3069.

[14] Ding Ning. Lifting permanent magnet for lifting scrap steel [P]. Chinese Patent: 02126633.6, 2004-01-28.

[15] Ding ning, Zhang ding-tong, Wang zuo-zhen. ANN Based Rare Earth Lifting Permanent Magnetic Chuck Design [J]. Applied Mechanics and Materials, 2014: 950-954.

[16] Ding ning, Song yu-mei, Wang li-na, etc. FEM-Based Lifting Permanent Magnetic Chuck Design [J]. Advanced Materials Research, 2013: 355-358.

[17] Ding ning, Zhang ding-tong. Energy-saving Rare Earth Lifting Permanent Magnet [J]. Advanced Materials Research, 2012: 391-394.

[18] Ding ning, Zhang ding-tong, Song yu-mei, etc. Lifting Chuck Design Based on Fuzzy Expert System [J]. Advanced Materials Research, 2013: 653-656.