POWER DISASSEMBLY EQUIPMENT FOR HIGH EFFICIENCY HEAT TRANSFER PLATE HEAT EXCHANGERS

by

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Plate heat exchangers are realized by means of a heat transfer mechanism, in which heat is naturally transferred from the hot substance to the object with a lower temperature according to the laws of thermodynamics. Two liquids of different temperatures flow on the wall, heat transfer on the wall and convection of the liquid on the wall, thus promoting heat transfer between the two liquids. Under the same flow rate and power consumption conditions, its heat transfer coefficient is three times that of shell and tube heat exchangers, which is a key and efficient new equipment for effectively using effective resources and saving and developing new energy. However the heat supply plate heat exchanger has a tiny circulation surface and is easily obstructed. Regular maintenance and cleaning, troubleshooting, and plate replacement all necessitate frequent heat exchanger disassembly and installation. The requirements and challenges in dismantling and assembling the heat exchanger are very high, and manual disassembly is wasteful, making consistent force difficult to achieve. The current methods of disassembly and assembly are inefficient and incorrect. The intelligent mechanization of disassembly and assembly equipment is realized in this paper by driving, clamping, automatic control, distance measurement, sensing, and other systems. The problems of uneven force, low efficiency, and precision in plate heat exchanger disassembly and assembly are solved. Our power disassembly equipment for high efficiency heat transfer plate heat exchangers not only enhances disassembly efficiency and precision, but it also ensures the safe operation of the plate heat exchanger heating system, and the heat transfer efficiency and heat exchange efficiency are improved. Furthermore, it has a wide range of applications in the petroleum, chemical, and other industries.

Key words: *plate heat exchanger, disassembly equipment, automation*

Introduction

With the advancement of society and the advancement of science and technology, human production and life are inextricably linked to the heating system. Because of the low temperatures in the winter, most places must rely on the heating system to keep people warm. Heating systems are also in a high demand in a variety of industries, including production and manufacturing. The heating system primarily supplies heat energy to users via the heat source, heating network. Plate heat exchangers are used to transfer heat energy and transfer heat, heat exchange when two different liquids under different temperature conditions, heat exchange will inevitably occur, two different temperature differences, in the forced convective heat exchange, through the structure of the heat exchange plate to improve the heat exchange efficiency, will also cause strong disturbance of the liquid, thereby reducing the thermal resis-

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tance of the boundary-layer, thereby improving the heat transfer efficiency. Many central heating systems used steam as a heat source in the past, but steam required high temperatures and pressure, therefore, the risk coefficient was very high. In recent years, high temperature water has gradually replaced the heat source of heating systems because the temperature and pressure required by high temperature water are relatively steady and safer.

Heat transfer application and disassembly of plate heat exchanger

As the central heating system's heat source transitions from steam to high temperature water, the heating and bath water heat exchangers have been gradually replaced by plate heat exchangers. Plate heat exchanger is composed of heat transfer plate, sealing gasket and pressing device. The key element of a heat exchanger is the heat transfer plate. The heat transfer plate can make the fluid strongly turbulent at low speed, so that the heat transfer is strengthened, and the plate stiffness can be improved, which can withstand large pressure. Plate heat exchangers have very high heat transfer efficiency, a large logarithmic mean temperature difference, and a relatively small occupied area. Plate heat exchangers employ circulating water pumps, which have variable frequency operation, low resistance, a compact structure, stable operation, automatic water supply and pressure stabilization, good heat dissipation, low loss, and a high utilization rate of cold-water area. However, because of the tiny circulation space between the heat exchange plates of the plate heat exchanger, it is easily blocked or scaled, therefore, the heat exchanger must be cleaned and descaled every time it is used. Furthermore, when leakage detection, deterioration of the sealing gasket, filtering failure, plate replacement, and so on occur, the heat exchanger must be disassembled and repaired. Plate heat exchangers have stringent disassembly and assembly requirements. When disassembling plates, sealing rubber strips, reaming rubber sleeves, and changing filters, uniform force and gentle tightening are required. Otherwise, the force applied to plate heat exchangers during tightening will be unevenly distributed, resulting in leakage, rubber strip crushing, and heat exchanger damage.

Although the plate heat exchanger is employed in many industries, its disassembly and assembly are time-consuming, labor-intensive, low in accuracy, and unequal in stress, making plate heat exchanger development slow. To overcome the problems associated with dismounting plate heat exchangers, improve dismounting efficiency and accuracy, save money, and ensure the safe and stable operation of the heating system, it is necessary and valuable to develop specialized equipment capable of dismounting plate heat exchangers with high efficiency and accuracy.

Research status of plate heat exchanger disassembly equipment

Wrenches and force-applying rods were once commonly utilized in manual disassembly and assembly. A plate heat exchanger required more manpower to disassemble and reassemble, and its efficiency was low. Furthermore, it was difficult for numerous persons to ensure that the clamping degree of each bolt was identical during manual operation during the plate heat exchanger clamping process, and it was easy to cause leakage and rubber strip crushing.

Currently, only two employees are required to install the plate-type heat exchanger, and installation efficiency may be raised by six times, addressing the issue of high strength physical strength required by manual disassembly of the plate-type heat exchanger. At the moment, the plate heat exchanger disassembly device is driven by a hydraulic cylinder rather than nuts and screws, which decreases worker workload. Furthermore, the dismounting device has a small volume, simple operation, and flexible movement.

However, the existing plate heat exchanger disassembly and assembly equipment is not precise enough, and its efficiency is rather low. It cannot adjust the fastening size accurately or monitor the parallelism of the pressing plates in real time. During the pressing operation, the movable pressing plates are frequently misaligned, resulting in unequal tension and leaks. The oil cylinder cannot be squeezed in synchronously to automatically adjust the fastening size, and some bolts have a high fastening size discrepancy. Furthermore, when the plate heat exchanger's data is irregular and there is a failure, it cannot provide an early warning and cannot conduct adequate rescue actions for the fault. The interior structure of the heat exchanger cannot be directly visible, and when a fault occurs, maintenance must be performed one by one to determine the problem, reducing the service life of the plate heat exchanger and the precision of disassembly and assembly efficiency [1].

We separate the disassembly process into six parts in order to design and produce high accuracy, high efficiency, and practical disassembly equipment: impetus, clamping, synchronization, ranging, sensing, and automatic control. In this paper, the oil pump of the drive system is updated, and the secondary pump is transformed into the tertiary pump, which cannot only conserve the flow but also enhance the rotation speed, thereby enhancing the work efficiency of the disassembly and assembly equipment. The tightness of each screw is within the allowable error due to the combination of distance measurement, synchronization, and driving system, and the oil cylinder can be positioned quickly and accurately after docking on the bolts, and the bolts can be tightened synchronously to ensure the same tightening torque of the bolts, thus improving the efficiency and accuracy of disassembling and assembling equipment. The sensing system is used to monitor the inclination degree of the plate in real time, ensuring that the plate remains parallel and in good position during the disassembly and assembly process, avoiding the disadvantage that the plate heat exchanger is inclined due to positioning error, avoiding the problem of uneven stress in the plate heat exchanger installation, and realizing precise control of the fastening torque and plate parallelism in the process. We can intuitively see the specific internal structure of disassembly equipment and plate heat exchangers through the automatic control system, set reasonable parameters to form an early warning mechanism, and provide real-time alarm to overload, failure, or unexpected events, thereby realizing safety monitoring, hidden trouble investigation, and abnormal early warning. Unexpected incidents can be dealt with using emergency dispatch and event tracking.

The plate heat exchanger disassembly and assembly equipment:
- that we invented has a basic structure and easy operation, which can considerably enhance disassembly and assembly efficiency,
- it has high operability and precision, avoiding leakage caused by improper exertion,
- it saves money, reduces energy consumption, and ensures the safe operation of equipment, and
- it is small in size, easy to carry, and can be applied to a wide range of working environments, with high popularization potential [2].

Energy power engineering and system functions of plate heat exchanger disassembly and assembly equipment

Function and working principle of each part system

Powertrain and energy efficiency

The dynamical system comprises of an oil pump, an oil cylinder, a distribution valve, a connecting pipe, and other components. Connect the oil cylinder and distribution valve to the oil pump first, then sleeve the oil cylinder on the heat exchanger's fastening screw, inject hydraulic oil into the oil tank, turn on the power supply, start the oil pump, use the motor to drive the internal hydraulic oil to the wrench through the oil pipe, and then push the hydraulic oil to the wrench's piston rod. The transmission shaft is driven by the ratchet on the wrench to start and stop the pressure of the oil cylinder, which is compressed by opening and closing the pressure, and the action is repeated until the appropriate size is obtained. To preserve the oil quantity in the oil tank at three-quarters capacity, do not refuel while there is pressure to prevent pressure in the oil storage line. The dynamical system enhances disassembly efficiency and reduces costs [3].

Clamping mechanism

A clamp and oil cylinders on both sides make up the clamping mechanism. Its primary role is to clamp the bolts and oil cylinders apply sufficient force to them in order to tighten, shift, and brake the bolts, allowing the bolts to be clamped and positioned, not loosen under specific external forces, and remain fixed on the plate heat exchanger.

The key to adjusting the clamping mechanism torque is determining the tightening torque. We employ a numerical calculation approach to establish the clamping mechanism's tightening torque, and the correct tightening torque will not cause the bolt to extrude and distort. The size of the bolt and nut determines the pressure on the bolt. We generated many alternate forces of various sizes based on the basic database of plate heat exchanger bolts and nuts. The M33 bolts are chosen based on the size and construction of the heat exchanger, and the lead P is 3.5. To prevent heat exchanger medium leakage, the bolt is tensioned on the plate heat exchanger. At the same time, the torque applied to the fixed plate's nut should overcome friction with the contact surface of the fixed plate, causing the tension of the bolt to exceed the preset load force of the bolt. In most cases, no more than 50% of the yield limit of bolt materials. The following is the formula for computing the bolt's torque, T [4]:

$$T = \frac{F}{12}\left(\frac{P}{2\pi} + \frac{RF}{\cos d} + sf\right) \tag{1}$$

where F is the tension on the bolt, usually 50% of the yield limit, P – the lead of bolt, R – the average radius from bolt center to thread contact point, d – the thread angle, usually 30°, s – the average radius of the nut, and f – the friction coefficient.

The performance grade of bolts mainly used in plate heat exchangers is 8.8, and the torque values of bolts with different specifications can be obtained by the aforementioned formula as shown in the following tab. 1.

The M33 bolt is finally chosen after several tests. Under the condition of mechanical lubricating oil and the size of M33 bolt, the lead P3.5, the friction coefficient, f, is 0.15, and the required bolt torque value is 1386 Nm. Choose the proper hydraulic wrench based on the bolt torque. The torque, T, required by the hydraulic wrench is typically in the 30-80% range, allowing the torque of the hydraulic wrench to be output most accurately.

In bolt connection structure, the relationship between bolt preload, tightening torque, nominal diameter of thread and torque factor is:

$$T = kMd \tag{2}$$

where T [Nm] is the tightening torque, k – the torque coefficient, M [kn] – the bolt preload, and d [mm] – the nominal diameter of thread.

The most difficult factor to calculate is the torque coefficient, k, which displays the link between the pre-tightening force and the torque to be applied during the fastening process.

Table 1. Torque values of bolts of different specifications

20	30	78991	228	283	369
Bolt inch [mm]	Hexagonal opposite side of nut [mm]	Bolt tension [N]	Torque value under various lubrication conditions [nm]		
			Molybdenum sulfide and graphite $f = 0.117$	Mechanical lubricating oil $f = 0.150$	Without lubrication $f = 0.200$
24	36	108983	363	454	589
27	41	142948	542	676	879
30	46	186301	791	989	1291
33	50	235385	1106	1386	1812
36	55	290204	1494	1878	2458
39	60	350753	1959	2466	3234
42	65	417037	2517	3173	4168
45	70	489056	3171	4001	5261
48	75	566806	3931	4964	6533
52	80	650286	4768	6037	7959
56	85	834452	6865	8704	11490
60	90	935133	8115	10293	13594
64	95	1041549	9505	12063	15939

Too much selection and calculating torque may easily damage nuts and washers. Too little selection will not fulfill the criteria of the sealing ring, resulting in leakage [4, 5].

The torque coefficient, k, is related to the bolt's structure and the friction coefficient of each friction pair, and its calculation formula is:

$$k = \frac{d_2}{2d}\tan(\varphi + p_v) + \frac{\mu}{3d}\frac{D_0^3 - d_0^3}{D_0^2 - d_0^2} \tag{3}$$

$$p_v = \arctan\mu_v \tag{4}$$

where d_2 [mm] is the thread pitch diameter, d_0 [mm] – the diameter of bolt hole, φ – the thread lift angle, p_v – the thread equivalent friction angle, μ_v – the thread equivalent friction factor, μ – the coefficient of friction between the nut and the supporting surface of the connected part, and D_0 [mm] – the outer diameter of the nut bearing surface.

Ordinary coarse teeth M16-M64 thread, the μ_v is between 0.1-0.2, and the middle number μ_v is 0.15, so the k is between 0.1-0.3, tab. 2.

Table 2. Tightening torque coefficient

Surface friction state	Finished surfaces		General finished surfaces		Oxidised surfaces		Galvanized surface		Dry rough surface	
	Lubricated	No lubrication	Lubricated	No lubrication	Lubricated	No lubrication	Lubricated	No lubrication	With	Without lubrication
Value	0.1	0.12	0.13-0.15	0.18-0.21	0.2	0.24	0.18	0.22	0.26	0.3

Since the bolt pairs used in practice are frequently machined using lubricating oil, k equals 0.13.

According to the stress of the bolt pair and the needed pre-tightening force for connection. Steel bolts made of alloy steel join the bolts. The tightening torque is based on the bolt's yield strength, and a yield strength of less than 80% is the pre-tightening force, with the torque as the basis. If the pre-tightening force is too great, the gasket will break and if the pressure exceeds the allowed pressure for an extended period of time, the bolt will break. Under normal conditions, the tightening torque should not exceed the allowed working temperature stress. Long-term work that exceeds the allowed stress will result in early breakdown of pressure-bearing elements, compromising production safety. As a result, the pre-tightening force of bolts at the working temperature should not exceed the permitted value, and the pre-tightening force at the working temperature of 90-95% should be used to compute the tightening torque. The pre-tightening force m of a steel bolt connection is typically computed

Carbon steel bolt:

$$M = (0.6 \sim 0.7)\sigma_S A_S \tag{5}$$

Alloy steel bolt:

$$M = (0.5 \sim 0.6)\sigma_S A_S \tag{6}$$

where σ_s [MPa] is the yield point of bolt material and A_s [mm^2] – the nominal stress cross-sectional area of bolts.

According to the mechanical design manual, the yield point σ_s of M33 bolt alloy steel is 640MPa, and the nominal stress cross-sectional area A_s of bolt is 694 mm^2, tab. 3.

Table 3. The *k* = 0.13 pre-tightening force and tightening torque value of bolt pair

Auxiliary bolt specification	Allowable preload [KN]		Allowable tightening torque [KN]	
	8.8S	10.9S	8.8S	10.9S
M11	27	38	36	60
M13	38	60	62	40
M15	72	110	160	220
M17	112	150	280	520
M19	139	180	385	530
M21	161	212	510	680
M23	220	280	780	1010
M25	258	340	1100	1465
M34	336	479	1500	1860
M37	348	520	1635	2450

Under the condition of bolt size M34 and bolt performance grade 8.8, through the calculation of bolt pre-tightening force and tightening torque, the allowable bolt pre-tightening force, *M*, is 326 KN and allowable tightening torque, *T*, is 1000 KN [6, 7].

Automatic control system

The automatic control system may automatically adjust, detect, and operate in accordance with the procedures and instructions set, allowing for automatic management, automatic operation, and maintenance without the need for monitoring. The main control platform of plate heat exchanger disassembly equipment is the automatic control system, which includes data acquisition, parameter display, function operation, early warning device, synchronous adjustment system, and other functions. On the display screen, the structure and measurement data of the plate heat exchanger are displayed. When a defect occurs, the exhibited structure allows the fault position be determined, and the plate heat exchanger may be correctly overhauled and treated. The automatic control system may store, query, and export measurement data for easy analysis and comparison, identify devices that are frequently prone to failure, and perform crucial attention and daily maintenance. The early warning parameters will be defined based on the measured data to form an early warning mechanism. When data deviation occurs during disassembly and assembly, and the detected data exceeds the upper limit, the fault signal appears in real time, allowing measures to be taken purposefully and pertinently, and emergency situations to be dealt with quickly, protecting the equipment as much as possible from the fault's damage. The automatic control system enables intelligent mechanization of disassembly equipment, which not only increases disassembly efficiency, saves resources and labor costs, and reduces labor intensity, but also ensures machine operation safety and extends plate heat exchanger service life. To achieve the preset parameters of the plate heat exchanger's fastening size, the controlled parameter is the heat exchanger's fastening size, the drive system is the execution unit, and the PID cycle control method is used to achieve accurate control, fig. 1.

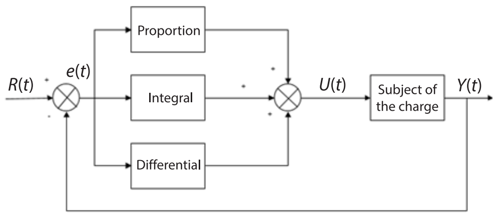

Figure 1. The PID loop control diagram

Key Technology of disassembly and assembly equipment of plate heat exchanger

Key technologies of high precision synchronous fastening

When the plate heat exchanger is mounted, the parallel movement of the movable platen is related to the rubber strip's service life and tightness. As a result, a combination of hydraulic drive, high precision tilt sensor, and intelligent electric control is used to investigate the method of synchronous control of disassembly and assembly equipment, as well as to monitor the parallelism of the two compression plates in real time, so that the load of the connecting bolts of the plate heat exchanger's movable compression plates is the same, and the two compression plates of the plate heat exchanger are nearly parallel, so that the sealing tape is not damaged and the risk of leakage medium is avoided.

Key technologies of automatic equalization adjustment

Tighten the plate exchanger diagonally and measure the inner distance between the two clamping plates in real time before installing the plate heat exchanger to ensure that the footage of each nut is balanced and the relative displacement variation is regulated within 4 mm. In this study, laser ranging technology is used to provide automatic and balanced adjustment of fastening size and pre-tightening force, thereby avoiding imbalanced footage of the plate heat exchanger nuts, which will result in plate heat exchanger leaking.

Digital twinning technology of board replacement structure

On the display terminal, the structure and measurement parameters of the plate heat exchanger can be viewed. The plate exchange structure can be simulated and images produced based on the structural type and bolt number of the plate heat exchanger. When an abnormal fault arises, the fault position can be diagnosed based on the structure by observing the structure and data of the plate heat exchanger in real time, saving time and labor. At the same time, the monitoring system may establish an early warning of plate exchange monitoring data, display the terminal alarm system, display the defect signal of heat exchanger disassembly equipment in real time, and perform historical inquiry. The clamping size and measurement data of the plate heat exchanger can be saved and exported.

Sustainability of disassembly and assembly equipment

The disassembly and assembly equipment of plate heat exchanger is small in volume and simple in structure, and can be used in different occasions and different objects, with wide application range and high working efficiency, moreover, the refitting and disassembly equipment also has good sustainable development.

Commonality

The equipment disassembly and assembly successfully overcome the difficulties of labor and low efficiency in disassembling and assembling the plate heat exchanger. It is difficult for numerous persons to ensure that the clamping degree of each bolt is identical during the plate heat exchanger clamping operation, resulting in leakage, rubber strip crushing, and so on. The nut types and sizes of fasteners on various plate heat exchangers varied, as do the nut sizes on plate heat exchangers with varying heating loads. The clamping mechanism and hydraulic wrench of the equipment are simple to use and suitable for nuts of various parameters, allowing it to meet the disassembly and assembly requirements of plate heat exchangers with various heat exchange areas while reducing the number of accessories of plate heat exchanger disassembly and assembly equipment. It can be used in a variety of working contexts because to its modest size and ease of transport. Mechanized disassembly and assembly equipment, which can be widely used in many regions where working circumstances are difficult and human labor is unsafe [8].

High efficiency

The equipment's hydraulic dynamical and automatic control system enable it to provide enough torque to overcome the fastening force of nuts, allowing it to meet the disassembly and assembly requirements of various types of plate heat exchangers. The laser distance measuring system is used to achieve accurate fastening dimension adjustment, and the synchronous control system is used to make the hydraulic system work synchronously, so that the tightness of each bolt is within the allowable error, effectively reducing plate heat exchanger leakage due to uneven stress, crushing of rubber strips, and so on, lowering labor costs and improving efficiency. Driving the hydraulic pump clamping mechanism increases fastening speed while decreasing labor intensity [9, 10].

Conclusion

In this paper, the power disassembly equipment for high efficiency heat transfer plate heat exchangers replace the secondary pump with the tertiary pump to increase the rotation speed of the oil pump and reduce the flow rate, improve disassembly and assembly efficiency while saving costs. Power engineering effectively converts electrical energy into mechanical energy, improves energy conversion and resource utilization, and saves the number of operators and disassembly time and costs. An intelligent system can prevent heat exchanger leaks or damage caused by uneven installation stress. Furthermore, real-time monitoring data from the distance measuring and sensing system can assure disassembly accuracy and reduce heat exchanger failure frequency. It demonstrates that the simulation's internal structure is straight and efficient, and display the simulated internal structure can directly and efficiently lock faults and deal with them in time. In the event of an abnormality or failure, the early warning mechanism can take reasonable steps to ensure the device's normal operation. However, it can also save a lot of personnel, improve equipment accuracy, make the equipment intelligent, and make all types of detection data obvious at a look.

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