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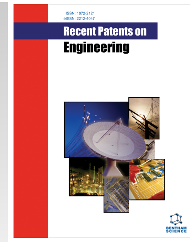
REVIEW ARTICLE



Review of Patents on Small Grinding Wheel Polishing Technology

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Abstract: Grinding disc polishing is an important polishing method that can be used to manufacture various high-precision and high-quality optical components. The smoothing effect of grinding discs is a simple and effective method widely used to suppress MSF errors. Grinding disc technology has good polishing effects on flat, spherical, aspherical, and free form surfaces. The polishing mechanism is to generate chips through the small plastic cutting of abrasive particles, but it only uses a very small amount of abrasive particles to exert force and uses the flow friction between the abrasive particles and the grinding disc and the workpiece to flatten the surface roughness of the workpiece. It can be seen from the relevant literature that the floating tool holder maintains a constant pressure to solve the problem of uneven pressure distribution between optical components. The adjustable tool holder can adjust the amount of spring deformation to adapt to local surface changes of optical parts, ensuring consistent material removal. The force-adaptive tool holder can be adjusted in real time during the machining process to reduce errors generated during machining. The jointed tool holder improves the fit between the grinding wheel and optical components, ensuring a tight fit between the grinding wheel and optical components.

This patent paper aims to introduce grinding wheel polishing technology as an essential method for manufacturing high-precision, high-quality optical components. It explores the optimization of abrasive tool design and the improvement of processing efficiency and proposes suggestions and prospects for future research, applications, and development.

Through querying literature and patent databases, patent documents related to grinding disc polishing technology were collected and analyzed. The design characteristics of the device structure, technological innovations, as well as the effectiveness and improvements in practical applications were focused.

Grinding disc polishing technology effectively removes surface defects and enhances the optical performance of optical components, particularly in suppressing MSF errors. This technology is suitable for flat, spherical, non-spherical, and freeform surfaces, with broad potential applications.

Despite the numerous advantages of grinding disc polishing technology, such as simplicity, effectiveness, and wide applicability, critical issues still need to be addressed, including surface morphology control, improving polishing efficiency, and enhancing consistency. Future research should focus on optimizing tool design and developing new polishing materials and processes to improve the manufacturing quality and efficiency of optical components.

Keywords: Grinding disc, optical components, device structures, polishing mechanisms.

1. INTRODUCTION

With the continuous development of polishing technology, the accuracy of polishing components is getting higher and higher, and the requirements for polishing tools are also getting higher. Polishing technology, as the final step in the processing of precision and ultra-precision components, constrains the surface quality, accuracy, and the entire processing cycle of the workpiece. With the emergence of technologies such as Computer controlled optical surfacing [1-6], Airbag Polishing [7-13], stress disc polishing [14-21], Magnetorheological Finishing [22-29], and Ion Beam Polishing

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[30-36], CCOS technology has developed rapidly. However, the new generation of large aperture optical systems has put forward higher requirements for the efficiency and quality of CCOS technology processing.

Polishing is a machining method that improves surface smoothness by achieving minor removal of the workpiece surface through mechanical and chemical reactions [37]. Medium and large aperture optical components with ultra smooth surfaces have great application prospects in various major engineering and cutting-edge technology fields. Hence, the research on precision machining technology of optical component surfaces is of great significance. With the rise of computers and related control technologies, several ultra-precision machining technologies, such as small grinding head polishing, have also emerged and developed rapidly.

The small grinding head technology is the earliest developed and most widely used computer aspherical surface forming technology, with a simple structure and a wide range of applications. The small grinding head technology uses a computer to control a grinding head (1/25~1/40) that is much smaller than the mirror size to grind or polish optical parts. The amount of material removed is controlled by controlling the residence time of the grinding head at different positions on the workpiece surface, which is the processing time and the relative pressure between the grinding head and the workpiece [38].

At present, grinding disc heads can be roughly divided into rigid, flexible, and semi-flexible according to their degree of softness and hardness [39-42]. The material for rigid tool polishing pads is generally iron, brass, or nickel binder. The flexible layer material of the flexible tool is rubber, sponge, or polyurethane. The polishing layer is made of polyurethane. The flexible layer material of the semi flexible tool is sponge, rubber or polyurethane, the thin plate is a metal sheet, and the polishing layer is polyurethane. This article categorizes and introduces the device structure, which can be divided into floating tool holder holders, adjustable tool holder holders, force adaptive tool holders, and joint connected tool holders [43]. This article introduces the principle of device structure and summarizes and analyzes representative patents of various polishing technologies. At the same time, some problems in the polishing process of various optical components were also analyzed. Finally, the development trend of polishing technology and processes was predicted.

2. OPERATIONAL PRINCIPLE

The working principle of the device structure is shown in Fig. (**1**). Floating tool holder holder is shown in Fig. (**1a**). This structure utilizes cylinders or pistons for translational motion, and the pressurized air stored in the pneumatic cylinder can adjust the position of the grinding disc. The cylinder or piston can maintain a constant pressure, and the grinding disc is connected to floating component 1—adjustable knife holder holder, as shown in Fig. (**1b**). The grinding disc to component 1 should be connected and the motion should be transferred to the tool through a flexible and adjustable device. Force adaptive tool holder. As shown in Fig. (**1c**), components 1 and 2 are rigidly connected to the grinding disc, forming a closed-loop control and feedback mechanism that can compensate for errors caused by machine motion in real time. The tool holder for joint connection is shown in Fig. (**1d**). Component 1 is fixed on the machine and connected to the tool through flexible joints that can change posture [43-47].

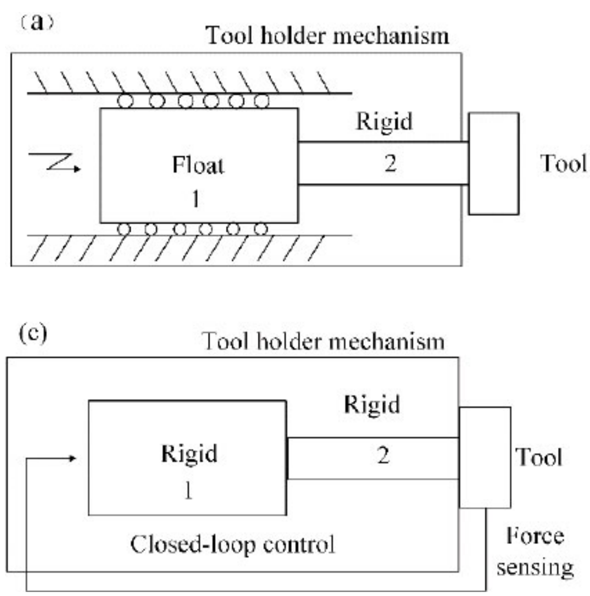

Fig. (1). Compliant grinding and polishing: A review (**a**) Floating tool holder, (**b**) Adjustable tool holder, (**c**) Force-compliant tool holder, (**d**) Joint-connected tool hold components and improve pressure stability during polishing [48-52]. The following is the research and analysis of the floating tool holder technology.

3. FLOATING TOOL HOLDER

The floating tool holder mainly uses a cylinder or piston to translate the grinding disc, and the pressurized air stored in the pneumatic cylinder can adjust the tool position. So, this tool can adapt to height changes on the workpiece while maintaining constant pressure. It can highly adhere to optical.

Yao Yongsheng [53] of Xi'an Institute of Optics and Precision Machinery, Chinese Academy of Sciences, and others invented a polishing device for aspheric optical elements, as shown in Fig. (**2**). The device mainly includes a cylinder, a rotating separation coupling, an electric motor, a polishing drive shaft, and a polishing disc. Two important factors affecting the quality of optical components are polishing speed and polishing pressure, which are controlled by the grinding head pressure through a cylinder. The increase in device volume and rotational inertia is not conducive to precision polishing and pressure control of optical components. This device solves the defect of large volume and difficulty in precise control of polishing devices in existing technologies.

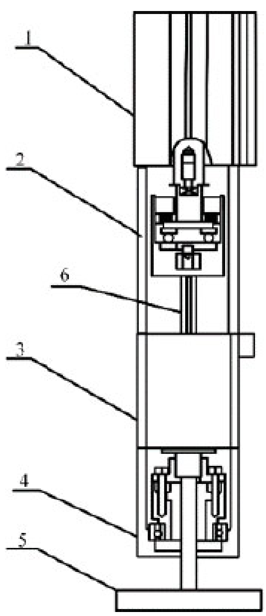

Fig. (2). A device for polishing non-spherical optical elements 1- Cylinder, 2- Rotary separation coupling, 3- Motor, 4- Collimating drive component, 5- Polishing disc, 6- Polishing drive shaft.

Zhang Chunlei [54] of Changchun Institute of Optics, Precision Mechanics and Physics, Chinese Academy of Sciences, and others invented an intermediate frequency error control device for aspheric optical elements. The device includes a lens clamping device, a lens rotating shaft, a polishing grinding head, a polishing pad, a cylinder, a grinding head rotating shaft, and a grinding head closing device. The polishing head of the device is attached to the polishing element through cylinder pressure. The use of large-sized rigid polishing heads enables the removal of material from the lens to be polished through rotation, and the polishing head properties enable mid-frequency error correction of aspherical optical components, which is of great significance for improving the quality of aspherical optical components and enhancing the performance of optical systems. This device achieves the removal of material from the lens to be polished through the relative motion between the polishing head and the lens to be polished. The smoothing effect is good, the polishing head is easy to make, the quality of aspherical optical components is improved, the optical system performance is enhanced, and the technical problem of suppressing intermediate frequency errors in existing aspherical polishing processes is solved.

Ye Qing [55] invented a cylinder stress polishing disc device for nonspherical optical components. The polishing layer of the device wraps around the bottom surface of the polishing main disc, ensuring even polishing at all points when in contact with the components, resulting in better smoothness and surface roughness of the polishing components. Ye Qing also proposed a polishing method. Firstly, the components are CNC polished with a small grinding head to achieve a machining accuracy of 500 nm. Then, magnetorheological surface polishing is performed to improve the surface accuracy of the polished components to 100 nm. Finally, surface error measurement analysis is conducted to determine whether it is qualified. The next step is to polish the cylinder stress plate, re evaluate whether it meets the requirements, and finally complete the work. The process of the device is reasonable. Firstly, through CNC polishing with a small grinding head, the damaged layer on the nonspherical surface is quickly removed. By performing several rounds of magnetorheological surface polishing, the surface accuracy can be improved. Finally, an iterative machining process was composed of magnetorheological surface polishing and cylinder stress polishing. Through multiple rounds of iteration, high-precision and ultra smooth polishing of non spherical surfaces was finally achieved, solving the technical defects of nonspherical machining that cannot effectively avoid smoothness and surface roughness.

Wang Fei [56] *et al.* invented an inline multi cylinder adaptive polishing device, as shown in Fig. (**3**). The device includes a flange base, an air chamber cover plate, an inline multi cylinder structure, and a polishing grinding head subunit. The upper ends of multiple sub cylinders of the device are interconnected, which can fully ensure consistent internal air pressure in the sub cylinders. The elastic coefficient of the air chamber can be changed by adjusting the air pressure in the cylinder as needed, which can solve the problems of uneven stress distribution and non adjustable elastic coefficient of the grinding head in the existing technology.

Cheng Haobo and others [57] invented an eccentric self--rotating pneumatic force applied large-diameter conformal polishing device, as shown in Fig. (**4**). The device includes a motor, rotary joint, sleeve, spindle, piston, ball head, polishing disc, snap ring, non Newtonian fluid, and conformal film. The polishing disc adopts an eccentric rotation structure, which can generate a Gaussian like removal function with a central peak. Compared with traditional rotary polishing devices, this device has a simple structure, saves costs, and solves problems such as the need for large diameter bearings and insufficient torque. By the action of the cylinder, the polishing film adheres stably to the optical surface, which can effectively suppress mid to high frequency errors. The device has a delicate structure, high degree of integration, and good stability, making it suitable for ultra precision surface processing of nonspherical optical components.

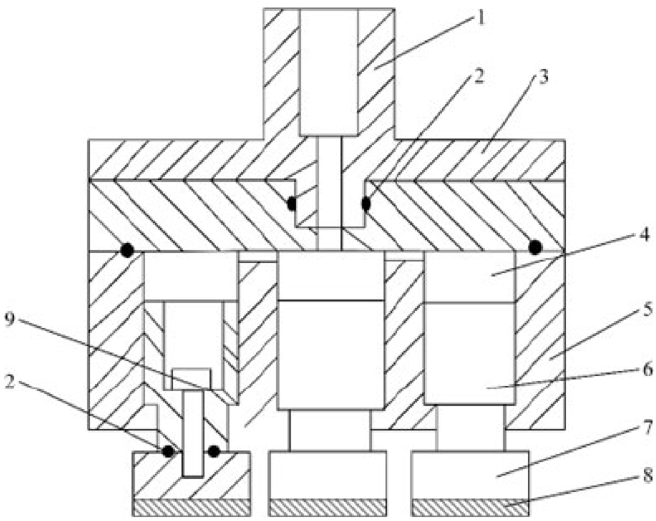

Fig. (3). An in-line multi-cylinder adaptive polishing head 1-flange base, 2- o-type sealing ring, 3- chamber cover plate, 4-sub cylinder, 5- inline multi cylinder structure, 6- sub piston base, 7-sub grinding head base, 8- sub grinding head polishing mold, 9- fastening bolts.

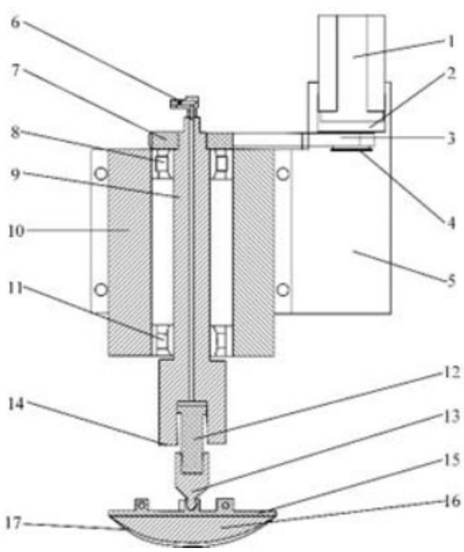

Fig. (4). A large-caliber shape-preserving polishing device with eccentric self-rotating pneumatic force application 1-motor, 2-motor seat, 3-belt, 4-motor pulley, 5-adapter plate, 6-rotary joint, 7-main shaft pulley, 8-main shaft upper bearing, 9-main shaft, 10-sleeve, 11-main shaft lower bearing, 12-piston, 13- ball head, 14- piston baffle, 15- polishing disc, 16- non Newtonian fluid, 17- conformal film.

Zhang Yun and colleagues [58] invented an air pressure--controlled constant-pressure self-adaptive polishing device, as shown in Fig. (**5**). The device's air pressure-controlled constant-pressure self-adaptive polishing head, when used for non-spherical surface polishing, presses against the workpiece surface. Compressed air stored in the cylinder maintains a constant air pressure, forming an air spring. The air pressure inside the cylinder can be adjusted as needed to change the elastic coefficient of the air spring, thereby obtaining an air spring structure with an adjustable elastic coefficient. Matching grinding head bases are made based on the closest spherical curvature radius of different workpieces. Through the flexible deformation of the flexible layer, the polishing layer is matched and fitted to the non-spherical surface contour. This device has the characteristics of a simple structure, constant and controllable pressure, and a close fit with the surface to be processed.

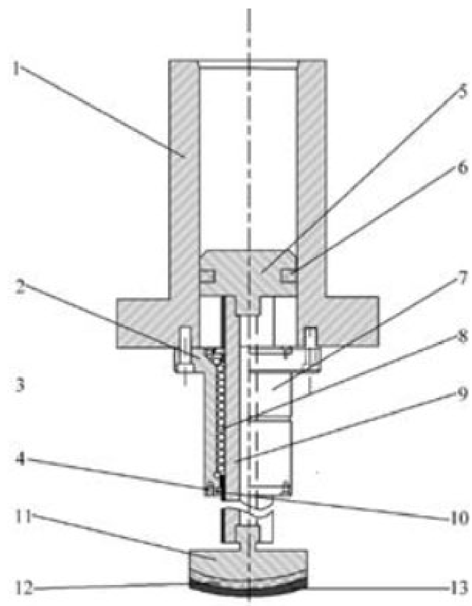

Fig. (5). A pneumatic pressure control constant pressure adaptive polishing head 1-spindle sleeve, 2- connecting flange, 3- fastening screw, 4- fixing screw, 5- piston, 6- sealing ring, 7- linear bearing, 8- roller, 9- tool spindle, 10- limiting flange, 11- grinding disc base, 12- flexible layer, 13- polishing layer.

Park Jong-woo *et al.* [59] invented a dynamic pressure floating polishing device, which can improve the polishing efficiency compared to traditional contact-type devices. It solves the problem of the position change of the polishing disk affecting the polishing accuracy, has a shock-absorbing and noise-reducing effect, and reduces the vibration amplitude of the polishing disk. This device overcomes the shortcomings of traditional polishing methods that cannot simultaneously consider processing quality and accuracy when reprocessing workpieces, providing a dynamic pressure floating polishing method that can reduce surface roughness, improve surface quality, and enhance accuracy when processing workpieces.

4. ADJUSTABLE TOOL HOLDER

The adjustable tool holder holder can be achieved by connecting the tool to the machine with an equivalent spring. The spring action can reduce the difficulty of adjusting the grinding head angle, adjust the deformation of the spring, ensure consistent material removal, and eliminate edge effects. It can be suitable for high-precision polishing or grinding [60-64]. The following is a study and analysis of the technology of adjustable tool holder holders.

Wang Junlin [65] and others invented a gap adaptive polishing device, as shown in Fig. (**6**). The device includes connectors, sealing rings, flexible spiral tubes, guide pillars, springs, retaining rings, grinding head seats, and grinding head bodies. The grinding head of this device can not only continuously provide polishing fluid from the center hole of the grinding head during the polishing process but also automatically compensate for errors caused by the machine tool, assembly, or the workpiece itself so that the gap between the grinding head and the workpiece remains consistent during the polishing process, thereby ensuring the quality of polishing. Solved the problem of uneven polishing fluid and the excessive gap between the grinding head and the workpiece during the existing polishing process.

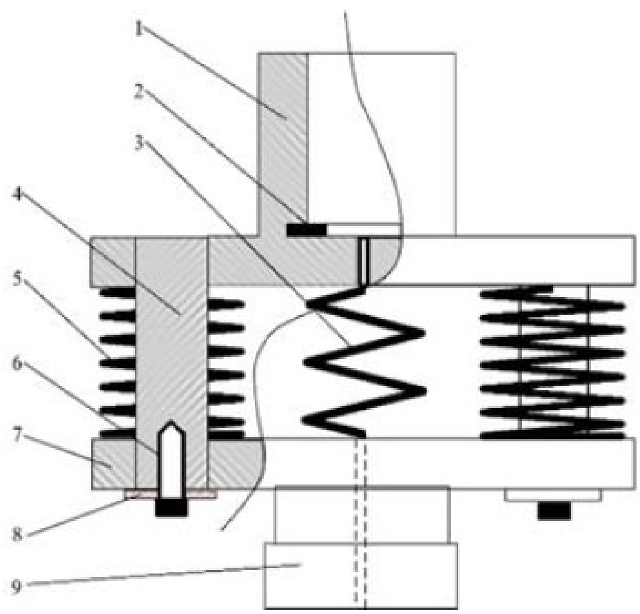

Fig. (6). A gap adaptive polishing head 1- Connection, 2- O-shaped sealing ring, 3- flexible spiral tube, 4- guide column, 5- spring, 6- screw, 7- grinding head seat, 8- retaining ring, 9- grinding head body.

Jiao Xiang [66] and others invented a floating grinding head and polishing head mechanism. The device mainly consists of grinding discs or polishing discs, transmission rotors, upper side plate bearing roller groups, lower side plate bearing roller groups, springs, and transmission pins. There are two sets of circular arc guide rails on the transmission rotor, and the axes of the cylindrical surfaces of the two sets of circular arc guide rails intersect vertically. The height of the grinding disc or polishing disc is adjusted to make the grinding surface or polishing surface pass through the intersection point of the axes. During grinding or polishing, the overturning torque can be eliminated, greatly improving the uniformity of grinding or polishing pressure and making the use of smaller grinding or polishing heads in floating machining a reality. This device is suitable for high-precision polishing or polishing.

Wang Junlin [67] of Changchun Institute of Optics, Precision Mechanics and Physics, Chinese Academy of Sciences and others invented an angle adaptive polishing device, as shown in Fig. (**7**). The device includes connectors, adjustment screws, springs, adjustment plates with countersunk holes, corrugated pipes, and grinding heads. In the actual machining process, angle deviation between the grinding head and the optical workpiece may occur due to errors in the machine tool, assembly, or the workpiece itself. The grinding head is divided into two levels of adjustment. Firstly, rotate the screws on the connecting parts to make the adjustment plate roughly parallel to the surface of the workpiece. Then, the flexibility of the corrugated pipe itself is relied on to achieve the adhesion between the grinding head and the surface of the workpiece. The device only needs to rotate the screws to complete rough adjustment and can adapt to the corrugated pipe itself, greatly reducing the difficulty of adjusting the grinding head angle and solving the technical problems of existing grinding heads with angle errors between the grinding head and the workpiece surface and poor polishing effect.

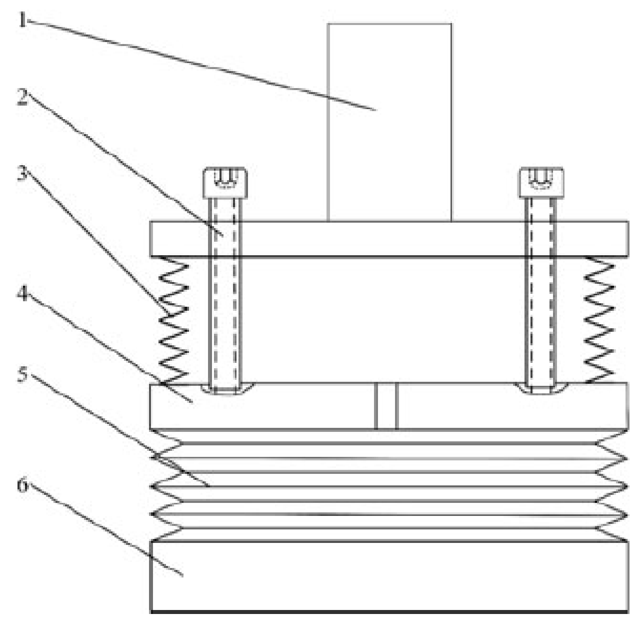

Fig. (7). An angle-adaptive polishing head 1- Connection, 2- Adjustment Screw, 3- Spring, 4- Adjustment Plate, 5- Bellows, 6- Grinding Head Body.

Yuan Baojun *et al.* [68] invented a flexible grinding head device suitable for single-sided polishing of silicon wafers. The device includes a driving plate, a transition plate, springs arranged in a circumferential direction between the transition plate and the driving plate, and a grinding plate. During the rotation process, the rotating spindle drives the driving disc to rotate, and the driving disc drives the transition disc to rotate. The transition disc drives the grinding disc to rotate through a flexible belt. The device improves product quality by adding transition plates, using flexible materials on the grinding plate, and avoiding traditional hard connections in the connection transmission, which affects the processing of the product.

Ke Xiaolong [69] and others invented a spring type center of gravity adjustable polishing disc mechanism device. The device includes a polishing disc, a power spindle, a spindle motor, a bracket, and a center of gravity adjustment mechanism. The center of gravity adjustment mechanism includes a telescopic motor, sleeve, spring, and pressure point components. This device replaces traditional edge polishing methods and is easy to control and operate. When the polishing disc moves to the edge area of the optical element, the polishing disc reduces the stress in the edge area of the workpiece through the action of spring elasticity, increases the stress in the middle area, and achieves reverse stress compensation. This can ensure that the removal amount of the edge area and middle area of the workpiece is consistent, ensuring processing efficiency while reducing or eliminating edge effect problems and achieving workpiece polishing processing. By using this device and its polishing method, as well as utilizing a telescopic motor in conjunction with a spring mode, edge effects can be reduced and real-time precise control can be achieved.

Rao Zhimin [70] and others invented a deformable flexible polishing device for processing large aperture optical elements, as shown in Fig. (**8**). The device includes polishing pads, support plates, barrel clamp nuts, connecting plates, cover plates, spring barrel clamps, and precision compression springs. The device adopts an elastic floating unit composed of precision compression springs with a simple structure that can replace springs with different stiffness coefficients, ensuring the reliability of the components and the flexibility of pressure adjustment. The arrangement of polishing discs in an array is beneficial for improving the practicality of polishing tools. The polishing pad has good adaptability to optical components, which is conducive to the effective adhesion between the polishing pad and the surface of the workpiece, increasing the effective removal area. The elastic floating units are uniformly arranged on the support plate, and precision compression springs with a certain stiffness coefficient are set inside each mechanism. The deformation amount can be adjusted and replaced according to the applied pressure to adapt to local changes on the surface of optical components. The effective adhesion between the polishing pad and the machining surface increases the effective machining area, while the high-speed rotation of the polishing tool significantly improves machining efficiency.

Wang Fei [71] and others invented an adaptive polishing device, as shown in Fig. (**9**). The device includes a flange base, a grinding head base, and a grinding head unit. During polishing, the sub-grinding head is pressed onto the optical workpiece, and each sub-grinding head undergoes elastic expansion and contraction between the processing surface and the base. The sub-grinding head adaptively moves to the sub base based on the polishing processing surface, improving the fit between the sub-grinding head and the polishing processing surface and improving the polishing quality. This device can be used for pre-polishing of nonspherical surfaces, with advantages such as high processing accuracy, simple structure, and reasonable design.

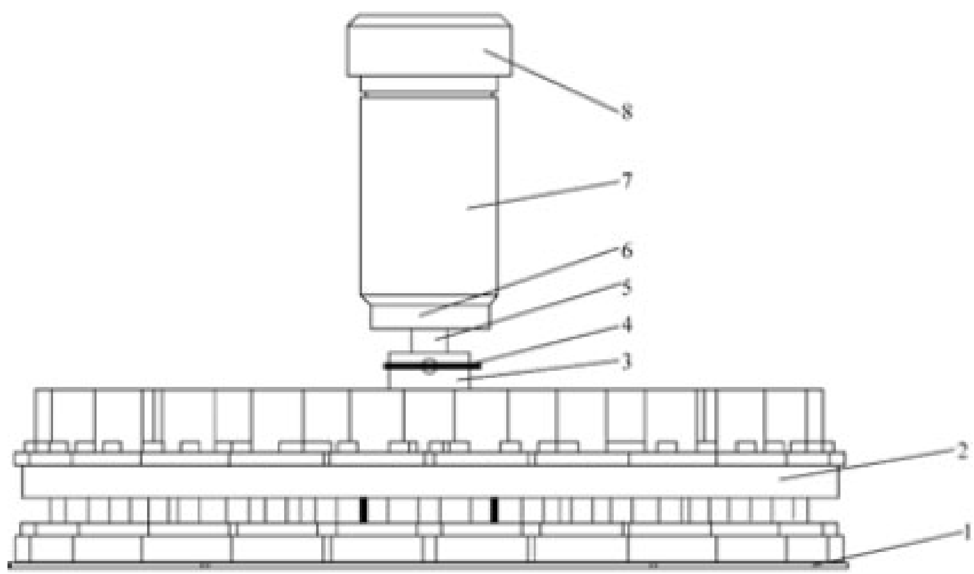

Fig. (8). A deformable flexible polishing tool for processing large-diameter optical elements 1- Polishing pad, 2- support plate, 3- axial connector, 4- elastic retaining ring, 5- ball spline shaft, 6- ball spline shaft sleeve, 7- connecting handle, 8- tube clamp nut.

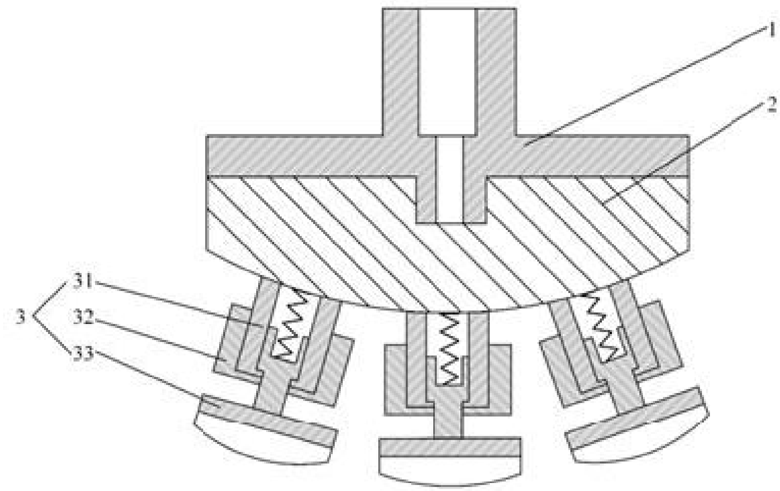

Fig. (9). An adaptive polishing head 1- flange base, 2- grinding head base, 3- grinding head unit, 31- sub base, 32-nsub grinding head, 33-sub base sleeve.

Wang Junlin *et al.* [72] invented a combined polishing head device. The device includes connecting screws, retainers, multiple grinding head cores, springs, and grinding head seats. The compression or stretching of the spring can change the expansion and contraction of the polishing disc while polishing and grinding can remove materials. The polishing tool composed of multiple grinding head cores has grooves, which can avoid slotting on the polishing mill, increase the service life of the polishing mill, and improve the stability of the removal function of the polishing mill head. There are springs on the grinding head core that can adaptively follow the surface shape of the workpiece, improving the fit. There is also a polishing fluid jet outlet in the holder, which can replenish and update the polishing fluid at any time. This device can improve the service life of the polishing die, enhance the stability of the grinding head removal function, and improve polishing accuracy.

5. FORCE-COMPLIANT TOOL HOLDER

The force adaptive tool holder has the characteristics of control and feedback. The control system can achieve constant machining force and real-time adjustment during the machining process, thereby reducing errors generated during the machining process, ensuring the surface quality of optical components, and achieving high-precision machining of optical components. The fit between the grinding disc and optical components can be adjusted to improve processing efficiency [73-77]. The following is the research and analysis of force adaptive tool retainer technology.

Wang Zhenzhong [78] and others invented a new type of airbag tool head device that can monitor and adjust its state. The device includes a semi-flexible spherical crown airbag shell, airbag tool head handle, pneumatic electric sliding ring, precision knife alignment device, and airbag tool head status monitoring system. This device combines its internal air pressure, the position of the airbag tool head on the machine tool, and its own temperature to coordinate real-time monitoring and control of various parts to complete precision and ultra precision polishing. The temperature status and force situation of the airbag tool head during operation are monitored in real-time through sensors, and the obtained status data is transmitted to the monitoring system for corresponding control measures. This device improves the reliability and stability of use, and monitors and controls the various states of the airbag through the detection device.

Wu Lixiang [79] others invented a polishing device to adjust the pressure distribution in the edge area of optical elements. The device includes a planetary dual rotor pneumatic transmission device, a joint type auxiliary pressure application mechanism, and a polishing disc. During the processing, it can cause edge protrusions, which is a common phenomenon known as edge warping. When the force gauge applies pressure on the outside of the workpiece, the pressure in the edge area of the workpiece is too high, which can cause the edge to collapse during the polishing process, which is a common phenomenon of "edge collapse". Adopting different pressure conditions for different situations can prevent the deterioration of edge surface shape. This device can adjust the pressure distribution in the edge area of optical components through polishing components, thereby changing the distribution of material removal in the edge area and suppressing edge effects. With the help of a joint--type auxiliary pressure mechanism, the vibration amplitude can be effectively reduced and the polishing quality can be improved.

Wu Lunzhe [80] others invented a flexible polishing device with polishing force control, as shown in Fig. (**10**). The device includes flexible tools, chuck seats, connecting plates, reducers, servo motors, frames, force sensors, force control systems, *etc*. During the polishing process, the force sensor tests the polishing force in real time and transmits the measured signal to the control system. The control system then processes the polishing force signal in real time and

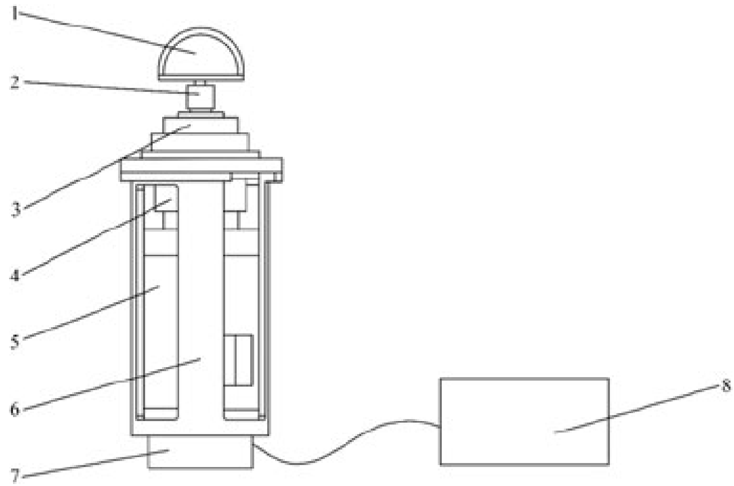

Fig. (10). Polishing force controlled flexible polishing tool 1- Flexible tool, 2- chuck seat, 3- connecting plate, 4- reducer, 5- servo motor, 6- frame, 7- force sensor, 8- force control system.

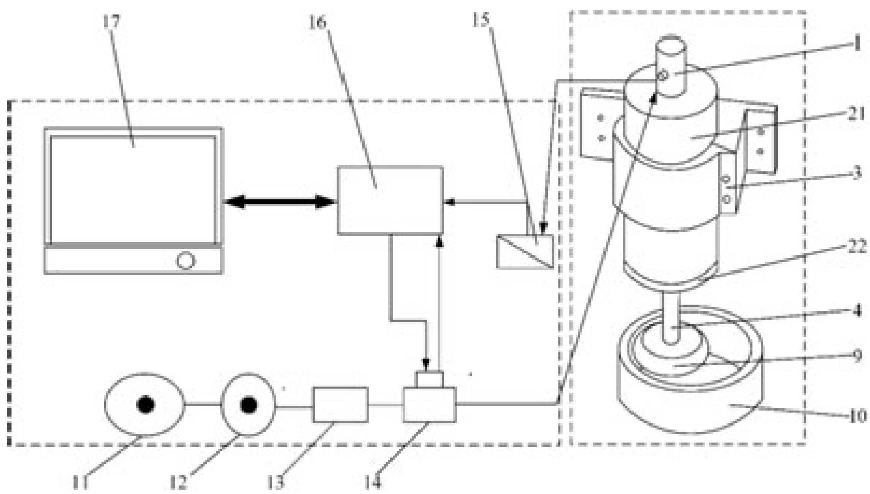

Fig. (11). A pneumatic controllable flexible grinding and polishing system 1- Pneumatic rotary joint, 21- Spindle housing, 22- Bottom cover, 3- Fixture, 4- Hollow metal rod, 41- Radial air outlet through-hole, 5- Upper rolling bearing, 6- Hollow rotary spindle, 7- Hollow motor, 8- Lower rolling bearing, 9- Metal rotary axle, 92- Airbag, 93- Grinding pad, 10- Deep cavity irregular workpiece, 11- Air pump, 12- Air storage tank, 13- Air source filter, 14- Electrical proportional valve, 15- Pressure sensor, 16- Data acquisition card, 17- Computer.

transmits the adjustment movement of the device during the machining process to the machining machine tool, adjusting the machine tool's motion trajectory. The device measures the polishing force in the process of processing through the sensor and achieves constant processing force through the control system. The surface quality of optical elements is guaranteed through the flexible layer to avoid intermediate frequency errors. The removal function is adjusted during processing to reduce the edge effect and achieve high-precision processing of optical elements.

Cao Zhongchen [81] and others invented a pneumatic controllable flexible grinding and polishing device, as shown in Fig. (**11**). The device includes a wheeled airbag polishing tool and a pressure control device. In the process of processing, the air pressure signal inside the airbag tool in the data acquisition link is converted into the air pressure analog signal through the air pressure sensor, and then the air pressure analog signal is converted into the air pressure digital signal, so that the real-time air pressure of the airbag polishing tool is fed back to the control center through data acquisition and data processing, compared with the preset air pressure, and then the air pressure digital signal is adjusted through data conversion. The data output obtains a simulated signal for adjusting the air pressure, completing real--time adjustment and stabilization of the internal air pressure of the airbag polishing device, and achieving deterministic and controllable flexible processing. This device provides real-time feedback and adjustment of the internal air pressure

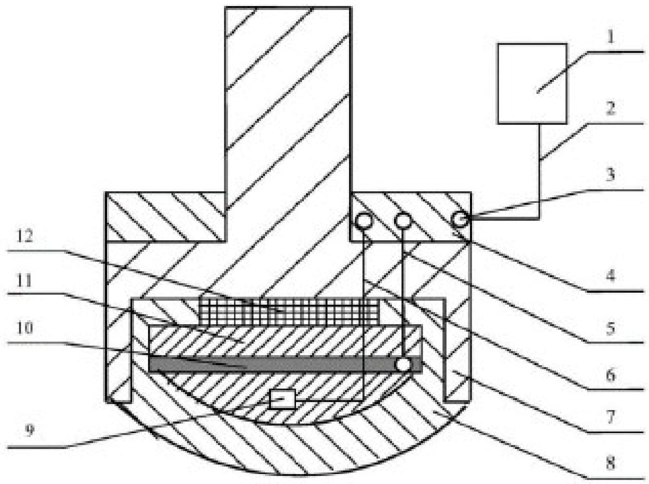

Fig. (12). A thermally controlled adaptive polishing head 1- Thermal control unit, 2-Thermal control signal transmission cable, 3-Electrical plug, 4- Conductive sliding ring, 5- Heating plate wire, 6-Thermal induction wire, 7- Flange base, 8- Asphalt polishing mold, 9- Temperature sensor,10- Heating plate, 11- Thermal field uniforming plate, 12- Insulation Plate.

of the airbag through a pressure control device, ensuring stable air pressure inside the airbag.

Wang Fei [82] and others invented a thermally controlled adaptive polishing device, as shown in Fig. (**12**). The device includes a flange base, a heating unit, a thermal control unit, and a polishing layer. The polishing layer of the device is an asphalt polishing mold, and the thermal control unit can control the temperature of the heating unit through temperature feedback from the temperature sensor. As the hardness of the asphalt material decreases with the increase of temperature, controlling the internal temperature of the asphalt polishing mold can achieve the adjustment of asphalt hardness. Due to the significantly higher internal temperature of the asphalt polishing mold compared to the external temperature, the contact part between the asphalt polishing mold and the aspherical surface has the lowest temperature and the highest hardness, forming a deformable contact hard shell. This not only maintains the hardness of the asphalt polishing mold at room temperature but also improves the adhesion between the entire asphalt polishing mold and the aspherical surface, which is conducive to achieving efficient surface processing of the aspherical surface. This device can effectively increase the contact area between the hard polishing die and the aspherical surface, control intermediate frequency error control, and improve machining accuracy.

6. JOINT-CONNECTED TOOL HOLDER

The tool holder for joint connection is a structure represented by a universal joint, which improves the fit between the grinding disc and optical components, provides different precession angles for optical processing, can rotate a certain angle, and can ensure the tightness of the grinding disc and optical components [83-87]. The following is a study and analysis of the tool retainer technology for joint connections.

Wang Junlin [88] and others invented and disclosed a cross articulated grinding head device, as shown in Fig. (**13**). The device includes a movable rod, U-shaped connector, pin shaft, grinding head body, and polishing mold. During the machining process, a reasonable structure of the grinding head is necessary to ensure a good fit between the polishing film and the machining surface. The horizontal and vertical pins can rotate the grinding head around the axis direction of the horizontal and vertical pins when the machining surface is not parallel to the polishing film, which can make the polishing film better fit the surface of the workpiece. The device is connected by a hinge joint formed by connecting parts and a pin shaft, which improves the adhesion between the polishing film and the machining surface, improves the polishing quality, and solves the problem of the polishing film and the machining surface subsiding and affecting the machining accuracy of the entire surface.

Hong Meijuan [89] of the Chinese Academy of Sciences Shanghai Institute of Optics and Fine Mechanics and others invented a combined grinding disc device for finishing large aperture aspheric components. The device consists of a central disc, a reinforcing plate, a fixed rod, a movable rod, and a ball joint polishing disc. During the machining process, the motor drives rotation, and the ball joint polishing disc synchronously processes a specific ring during the rotation process. This device achieves mechanization and controllability during precision polishing. During the processing, the ball joint polishing disc applies a fixed load to the optical components, avoiding reliance on manual experience, improving processing efficiency, and reducing human labor.

Cheng Haobo [90] and others invented a multi-degree-of-freedom pneumatic flexible polishing tool device. The device mainly consists of a rotating mechanism, parallel mechanical arm mechanism, wrist swinging mechanism, transmission mechanism, and pneumatic polishing tool head. The device is driven by servo motors, which can make the tool head swing around the wrist to achieve angular

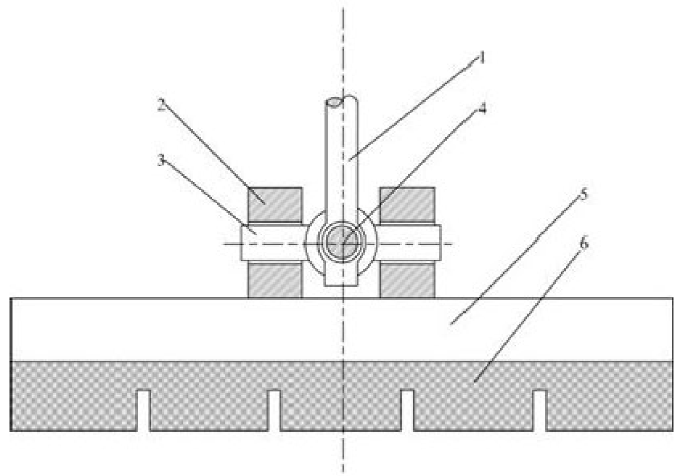

Fig. (13). A cross-hinged grinding head 1- Active rod, 2- U-shaped connector, 3- horizontal pin shaft, 4- vertical pin shaft, 5- grinding head body, 6- polishing mold.

motion, providing different machining angles for optical processing. The device can grind and polish workpieces with a compact structure, simple device, and good flexibility. It can determine various experimental parameters for different processes through experiments, providing a strong guarantee for simpler and more effective processing in the future.

Zhang Haitao [91] invented an asphalt polishing device, as shown in Fig. (**14**). The device includes a spindle body, a rotating spindle, a clamping structure, an airbag unit, an eccentric motion unit, and a swinging mechanism. During the work process, the airbag inflates and maintains a certain pressure. The rotating spindle rotates at a certain speed, driving the polishing head of the airbag unit to rotate. The polishing head drives the components in the eccentric motion unit to rotate. The rotating pair in the components achieves translational motion under the joint action of the ball joint mechanism and the swing mechanism and cannot rotate. The device achieves the translational movement of the polishing disc through the joint action of various mechanisms, and the airbag also achieves constant and controllable pressure.

Wang Yaliang [92] and others invented a spiral grinding disc device. The device includes a grinding disc, a rotating device, and a workpiece feed mechanism. During the machining process, the motor drives the grinding disc to rotate. When the grinding disc rotates, the workpiece mounting head will move horizontally with the baffle. The workpiece mounting head can drive the entire workpiece to rotate around the rotating seat, achieving the movement of the grinding disc from the outer ring to the inner ring. The system moves under the action of the cylinder seat, enabling the workpiece installation head to enter and leave the grinding disc. The device has a simple structure, low cost, high degree of automation, high processing efficiency, and good quality.

Mao Meijiao [93] and others invented a flat polishing device. The device includes a body, a motor, a polishing disc, an eccentric cam push rod mechanism, a crank slider mechanism, and a screw lifting mechanism. During the machining process, the motor drives the polishing disc to rotate, and at the same time, the cam push rod moves horizontally. The cam push rod is rigidly connected to the slider to drive the crank to rotate, and the screw lifting mechanism and the workpiece fixing plate work together to rotate. The relative motion between the workpiece on the fixed disc and the polishing disc completes the polishing process. This device can control the relative movement between the polishing disc and the workpiece and can apply a thrust between the polishing disc and the optical element, making the workpiece movement more stable and continuous, reducing production costs, and improving polishing quality and efficiency.

Wen Donghui [94] and others invented a hydraulic pressure suspension polishing integrated machining gap adjustable device. The device includes a polishing disc, a hydraulic pressure suspension device, a lifting device, a pressure detection device, a machining gap adjustment device, and a support device. During the processing, the surface of the polishing disc has a certain slight inclination angle. As the universal floating joint can rotate at a certain angle, the connection between the universal floating joint and the polishing disc ensures a tight fit. When this device is in operation, the motor drives the entire hydraulic pressure suspension device and polishing disc to move downwards along the linear guide rail. The control panel inputs parameters to control the up and down movement of the polishing disc. The coupling and spring group are connected to the polishing disc, indirectly driving it to rotate. The force of the floating plate is collected and recorded by the force sensor, which is the same as the buoyancy force of the liquid, achieving stable operation of the device and ensuring high precision of polishing processing. The device has a simple and compact structure, low equipment cost, and improves machining accuracy.

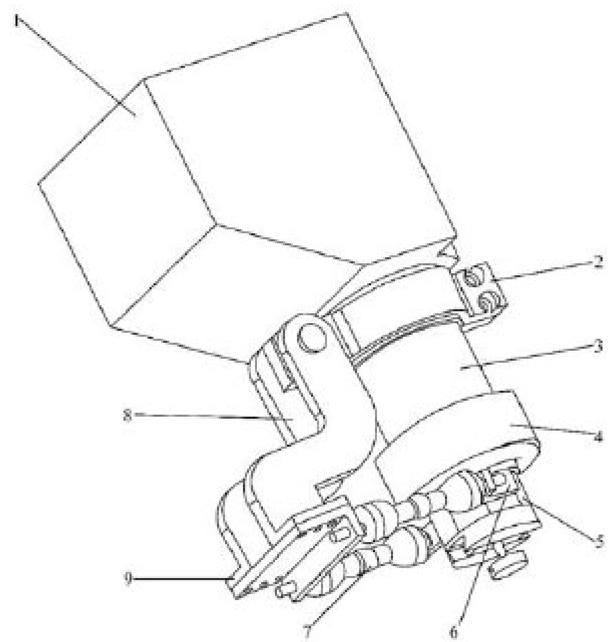

Fig. (14). An asphalt polishing device 1- Main spindle body; 2- Clamping structure; 3- Rotating spindle; 4- Airbag unit; 5- Eccentric motion unit; 6- L-shaped components; 7- Ball joint mechanism; 8- Swing mechanism; 9- Right angle fixing plate.

CONCLUSION

The main patents studied in this article are the structure of the device: floating tool holder, adjustable tool holder, force adaptive tool holder, and tool holder connected by joints. These structures can improve machining accuracy, polishing quality, and machining efficiency.

Yao *et al.* solved the problem of large volume and difficulty in precise control of the polishing device by controlling the pressure of the grinding head through a cylinder. Wang *et al.* solved the problems of uneven stress distribution and nonadjustable elastic coefficient of grinding heads in existing technologies by adjusting the air pressure inside the cylinder to change the elastic coefficient of the air chamber. Cheng *et al.* used a cylinder to ensure stable adhesion between the polishing film and the surface of optical components, effectively suppressing medium to high frequency errors. Zhang and his team adjusted the air pressure inside the cylinder as needed to change the elastic coefficient of the air spring, which can solve the problems of unstable polishing pressure and uneven pressure distribution between the grinding disc and optical components in existing technologies.

Jiao *et al.* made the use of smaller grinding or polishing heads in floating machining possible through the action of springs, making it suitable for high-precision polishing or grinding. Wang *et al.* reduced the difficulty of adjusting the angle of the grinding head and solved the problem of angle error and poor polishing effect between the existing grinding disc and the surface of the workpiece through the adaptive use of the corrugated tube itself. Ke *et al.* can achieve consistent removal of the edge and middle areas of the workpiece through the action of spring elasticity, ensuring machining efficiency while reducing or eliminating edge effect problems. Rao *et al.* can replace and adjust the deformation amount according to the applied pressure by setting a precision compression spring with a certain stiffness coefficient to adapt to local changes on the surface of optical components.

Wang and his team used detection devices to monitor and control the various states of airbags, improving their reliability and stability in use. Wu *et al.* achieved constant machining force through a control system, ensured the surface quality of optical components through a flexible layer, avoided intermediate frequency errors, reduced edge effects, and achieved high-precision machining of optical components. Cao *et al.* obtained simulated signals for adjusting air pressure through data conversion and output, and completed real-time adjustment and stabilization of the internal air pressure of the airbag polishing device, achieving controllable flexible machining. Wang and his team controlled the internal temperature of the asphalt polishing mold to adjust the hardness of the asphalt. This not only maintained the hardness of the asphalt polishing mold at room temperature, but also improved the adhesion between the asphalt polishing mold and optical components, thereby improving processing efficiency.

Wang and his team improved the adhesion between the grinding disc and optical components through articulated connections, thereby enhancing the polishing quality. Cheng and his team use servo motors to drive the tool head around the wrist to achieve swinging motion, providing different precession angles for optical processing. Zhang and his team achieved translational motion of the grinding disc through the joint action of the ball joint mechanism and the swinging mechanism, but it could not rotate. Wen and his team can rotate a certain angle through the universal floating joint, ensuring a tight fit between the universal floating joint and the polishing disc.

During the processing, we can choose different polishing discs based on the required surface accuracy and quality, as well as manufacturing costs.

CURRENT & FUTURE DEVELOPMENTS

After organizing relevant literature on polishing tools, I have gained a certain understanding and knowledge of polishing tools. Now, I summarize the current technical status.

As the polishing process progresses, the abrasive tools gradually wear down, leading to a decline in polishing effectiveness and affecting the smoothness and integrity of the workpiece surface. This wear not only reduces the lifespan of the abrasive tools but also increases the cost and time required for the polishing process. By improving the materials and structural design of the abrasive tools, as well as optimizing polishing parameters and processes, wear can be reduced, and polishing efficiency and surface quality can be enhanced. This will help achieve higher precision and productivity in high-temperature alloy machining [95-101].

At present, the factors that affect polishing accuracy include grinding discs, polishing paths, grinding fluids, *etc*. The materials used for grinding discs mainly include asphalt, polyurethane, *etc*. Different grinding discs are selected for different optical components. Therefore, people continuously optimize and improve the device structure to improve processing efficiency and accuracy.

The demand for ultra precision machining technology and processes in the high-tech field is extremely high, and the requirements for surface quality and machining damage of components are also increasing. Through discussions on patents both domestically and internationally in recent years, the following prospects have been made for polishing tools:

[1] Improve the polishing device. It is necessary to simplify the polishing device, reduce costs, improve the stability of polishing pressure, and enable flexible control of pressure magnitude.

[2] Improve polishing tools. Improve the adhesion between polishing tools and workpieces, distribute stress evenly, enhance the tool's removal ability, shorten polishing time, improve polishing efficiency, and reduce edge effects during the polishing process of workpieces.

[3] A combination of multiple polishing tools. The polishing function of polishing discs is single and needs to be combined with other polishing methods to adapt to the processing of various complex workpieces, especially the processing of opposite components. At present, the processing methods for heterosexual components are not mature, but various high--tech technologies require high-precision heterosexual components, which is a major trend for future development.

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G.L. and K.Z. contributed to the research design and implementation, as well as the data analysis and manuscript writing.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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