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ROCKWELL HARDNESS UNMANNED PRECISION METERING CALIBRATION DEVICE

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Abstract:
Based on the concept and technology of precision metering and intelligent metering, this research combines high-precision force loading technology, indentation measurement technology, automatic control technology and robot technology. An unmanned precise measurement and calibration device for Rockwell hardness is designed and developed. The design scheme and research results are given. The test results show a high measurement accuracy of the device, and it has obvious advantages in the standardization and consistency of the test process. The completion of this device has made a great breakthrough in the work of hardness measurement and calibration and provided a good direction for the development of other parameter unmanned precision measurement and calibration.

Keywords: Hardness measurement, Rockwell hardness, Unmanned, Calibration device

1. INTRODUCTION

Rockwell hardness is an index to determine the hardness value by the depth of plastic deformation of indentation. Rockwell hardness is widely used in aerospace, automotive, marine, instrumentation and other manufacturing industries. Almost 70% of raw materials and parts require Rockwell hardness test, and the accuracy and efficiency of the hardness test results have always been the goal pursued by hardness measurement personnel[1]. At present, the degree of automation of Rockwell hardness standard machine is relatively low. In the process of pressing the Rockwell blocks, the replacement of different Rockwell hardness blocks and the transformation of different indentation positions on each hardness block are all manually operated, which seriously affects the completion rate of the measurement task.

At present, automatic measurement of single indentation point has been realized in hardness measurement, including automatic force loading and automatic indentation measurement. But there is no multi-indentation point, multi-hardness block automatic measurement device. Based on the load sensor and differential sensor, Liang Weichao [2] realizes the load and depth measurement of the force through the PID algorithm and carries out the automatic control of Rockwell hardness detection. Hruz [3] et al. used particle swarm optimization to automatically measure the hardness of samples with poor surface quality. At present, the one-key operation of hardness measurement force value loading and indentation measurement has been achieved. Balogh [4] et al. studied the combination of the manipulator arm system and soil hardness measuring instrument to realize the automatic measurement of soil hardness. With the development of mechanical automation technology, the automatic feeding technology using mechanical arm has gradually matured. Therefore, the use of mechanical arm to replace manual movement of the dot position and manual loading and unloading of the hardness block can not only improve the efficiency of measurement calibration, but also improve the accuracy of measurement due to the reduction of human involvement.

With the development of precision measurement and intelligent technology, this research combines the advantages of the two technologies well and is the first to apply the manipulator to the Rockwell hardness standard device. It also realizes the unmanned precision measurement calibration of the Rockwell hardness blocks. It can not only implement the automatic sample of multiple Rockwell hardness blocks, but also automatically complete the automatic transformation of different pressure points of each Rockwell hardness block, which would dramatically increase automation, free up manpower and resources, improve the comprehensive technical ability of Rockwell hardness machine and the overall quality of the system.

2. DEVICE DESIGN AND DEVELOPMENT

2.1. Overall Technical Solution

The overall technical scheme is shown in Figure 1. The overall structure of the device is mainly composed of intelligent loading laser Rockwell hardness measurement system, robot automatic feeding system and interactive control system. The intelligent loading laser Rockwell hardness measurement system includes force loading system and indentation depth measurement system. The robot feeding system consists of the robot body, the grab, the sample loading system and the secondary positioning system. Interactive control system includes computer control system, robot control system and interactive communication between them.

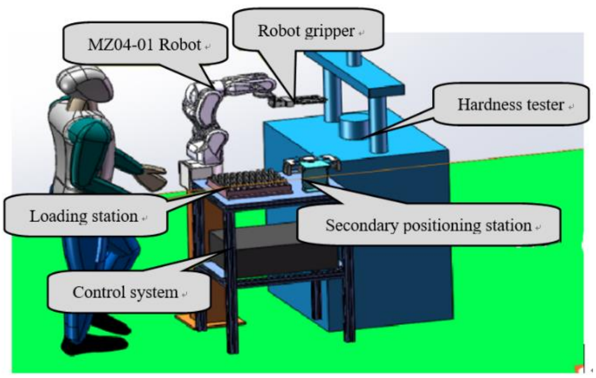

Figure 1: Overall technical solution

The Rockwell hardness automatic calibration device designed in this paper can grasp and move hardness blocks of different shapes including rectangle, circle and ring smoothly and accurately. The precision of the manipulator to move the hardness block is ± 0.1 mm. The mass of the workpiece can reach up to 1 kg. Therefore, this device can realize the automatic grasping and moving of all Rockwell hardness blocks. Rockwell hardness measurements with rulers of HRA, HRB and HRC can be achieved.

2.2. Subsystem Technical Solution

2.2.1 Intelligent loading laser Rockwell hardness measurement system

The intelligent loading laser Rockwell hardness measurement system is shown in Figure 2, including two parts. The first is the intelligent force loading system, which uses a motor to drive the screw to drive the weight to rise and fall to load and unload the test force, so as to obtain the accurate test force value. The whole process of force application is monitored and fed back through a high-precision force sensor to achieve intelligent control in the whole process. The second is the indentation depth measurement device. The laser Michelson heterodyne interference system installed above the spindle follows the displacement movement of the spindle and measures the depth of indentation in real time. The whole test process realizes one-key automatic operation.

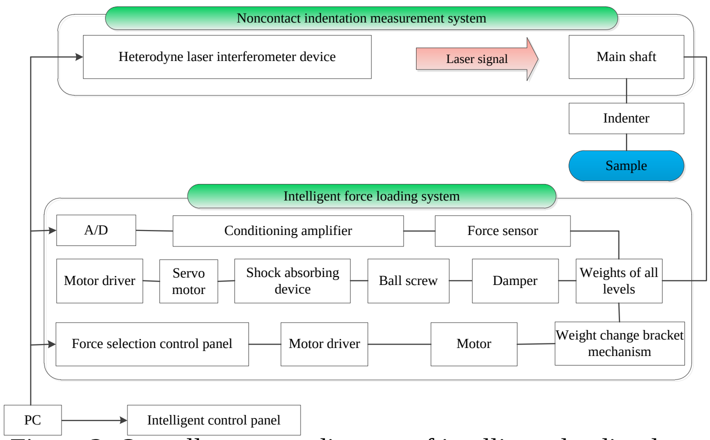

Figure 2: Overall structure diagram of intelligent loading laser Rockwell Hardness standard device

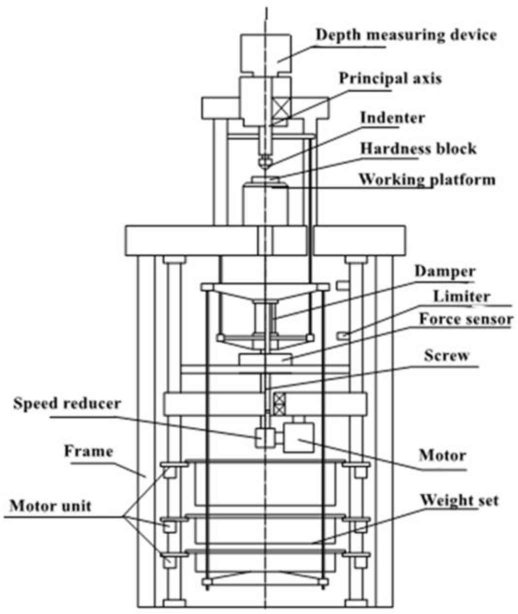

Figure 3: Rockwell hardness measuring device

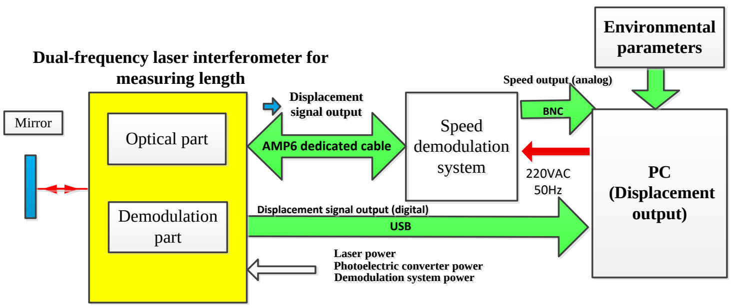

Figure 4: Scheme diagram of dual-frequency heterodyne laser interferometer system

The structure diagram of force loading system is shown in Figure 3. When the motor starts to work, it drives the synchronous ruler belt, reducer and ball screw to rotate, and the screw mother moves downward in a straight line. The weight of the small hanging and connecting parts on the motor is loaded onto the main shaft to realize the initial load. The screw mother continues to move downward in a straight line, and automatically controls the variable load motor set to release the first-level weight. The main shaft is loaded with the weight of the large crane and its connectors and the first-level weights to realize the first-level loading. The screw mother continues to move downward in a straight line, and the second weight of the variable load motor set is automatically controlled. The second level weight is loaded onto the main shaft to realize the second level loading; The loading speed of the whole loading process is controlled by the sensor's feedback to the loading force value.

The laser indentation depth measurement system adopts the principle of dual-frequency heterodyne laser interferometer. The schematic diagram of the system scheme is shown in Figure 4. The dual-frequency length measuring laser interferometer takes the optical head and demodulation system as a whole, takes the plane mirror as the cooperative measuring target, and directly outputs the displacement digital signal to the computer. The computer collects the environment temperature and humidity and air pressure, compensates the displacement automatically by software, displays the displacement measurement result directly, and gives the real-time curve of displacement. Speed demodulation system as an independent function module, an extension of the system function, can directly obtain the speed output (analogy signal).

There was no direct mathematical model for Rockwell hardness test. According to various factors affecting hardness measurement, the following functions could be considered:

$$HRC = f(F_0, F, r, \alpha, t_0, t, L) \tag{1}$$

Where: *HRC* -- Rockwell hardness value;

F_0、F -- initial test force, total test force;

R、α-- conical Angle of the head, radius of arc;

t_0、t -- retention time of initial test force and total test force;

L - Residual indentation depth.

The GUM uncertainty evaluation method was used to evaluate the uncertainty of Rockwell hardness. According to the requirements of the international Rockwell hardness definition, the uncertainty propagation coefficient of each component was determined. The influencing factors included: initial test force, total test force, indenter angle, indenter radius, initial test time, main test time and the error of the depth measurement system.

Deviations included test deviations and deviations from standard gauges. The standard uncertainty of each factor was obtained through the uncertainty synthesis of the deviation of each factor, as shown in Table 1. The uncertainty propagation coefficient of each component defined by the international definition could be used to calculate the uncertainty component of each influencing factor to hardness.

Since each component was independent and unrelated, the uncertainty of synthetic standard could be calculated as follows:

$$\mu^2(H) = \sum c_i^2 \mu^2(x_i) \tag{2}$$

The uncertainty of the synthetic standard of the device in this study was:

$$\mu_c(H) = \sqrt{\sum c_i^2 \mu^2(x_i)} = 0.098HRC \tag{3}$$

When k =2, the extended uncertainty U of the automatic sample loading hardness measuring device was:

$$U = k \times \mu_c(H) = 0.2HRC \tag{4}$$

2.2.2 Automatic feeding system of robot

Nachimz04-01 series is selected as the robot body, and the appearance diagram is shown in Figure 5. It is small and compact, free of installation conditions, and can be adapted to any installation conditions; The cable of hollow wrist can avoid interference and improve the reliability of arm wiring. It has a smooth body, which reduces the concave and convex feeling of the robot surface and makes it easier to clean. It has fast action

Table 1: Summary table of standard uncertainties

Influence	Symbol/Unit	Error/um	Uncertainty	Coefficient	U^2
Initial Forch	F_0/N	0.03	0.016	0.17	7.40E-06
Total Force	F/N	0.09	0.051	-0.08	1.66E-05
Indenter Angle	α/°	0.09	0.05	0.36	3.24E-04
Indenter radius	r/μm	1.4	0.80	0.1	6.40E-03
Initial time	t_0/s	0.5	0.29	0.016	2.15E-05
Total time	T/s	0.3	0.17	-0.05	7.23E-05
Deep measurement	L/μm	/	0.05	-1	2.50E-03

performance, which is the fastest robot of the same level, which is helpful to improve the production efficiency. It can support various applications, such as providing vision Sensors, force sensors, additional shafts and other specifications.

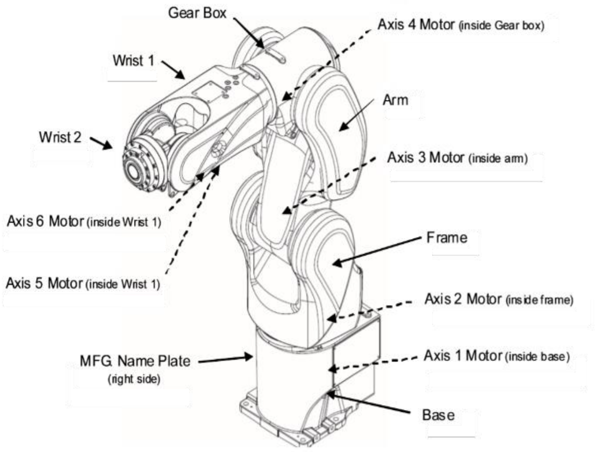

Figure 5: Mz04-01 Robot body appearance diagram

The robot gripper is composed of a grab driver and a grab:

1)Fetch driver: The design of fetch gripper of the robot needs to grasp and move different shapes of hard blocks smoothly and accurately. According to the known conditions: the maximum workpiece quality is considered as 0.5 kgf, and workpiece size is biggest Φ 60 mm * 10 mm. The inner diameter clamping method is adopted, and the clamping point position is calculated as 92.5 mm. When the pressure is 0.6 MPa, the clamping force of the inner diameter is 60 N and the friction coefficient is 0.25. Considering the impact of acceleration, the actual clamping force is calculated to be 2.72 times of the required clamping force by taking into account acceleration and the time to accelerate to the maximum velocity of 600 mm/s is 0.5 s. Therefore, it is more appropriate to adopt MHKL2-25D large-stroke pneumatic clamping jaw of SMC as handling drive, and its appearance diagram is shown in Figure 6. It adopts a rigid wedge structure, so there is no lateral swing in the direction of travel after holding the workpiece. Due to the built-in air claw speed regulating needle valve, the close speed of air claw can be adjusted; Combined with sliding bearing guide, the running rigidity and smoothness of the gripper are increased. The repeatability can reach ± 0.01 mm. Through the closed dust cover can prevent dust, water and other into the main body, but also can avoid the dust and grease produced inside the air claw flying[5].

Figure 6: MHKL2-25D appearance diagram

2) In order not to damage the operating surface of the hardness block, the robot gripper adopts 2A12 hard aluminium block as the main material. With the surface anodizing treatment, the weight of the gripper is greatly reduced without reducing the strength of the gripper. Schematic diagram of gripper is shown in Figure 7.

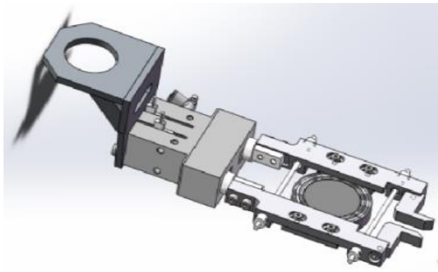

Figure 7: Schematic diagram of gripper

The material placement system is used for placing samples to be tested and samples that have been tested. To ensure that the hardness block is easy to hold, the test sample block should be placed vertically as shown in Figure 8. The manual feeding platform adopts a 4040 aluminium profile as the main structure. Workpiece tray is made of nylon 1010 as the base material. The tray can carry 42 workpieces (3×14) at a time, which can achieve zero scratch on the workpieces. The control system is loaded on the main structure of the material placement system[6], which greatly reduces the occupied space of the equipment and improves the operability.

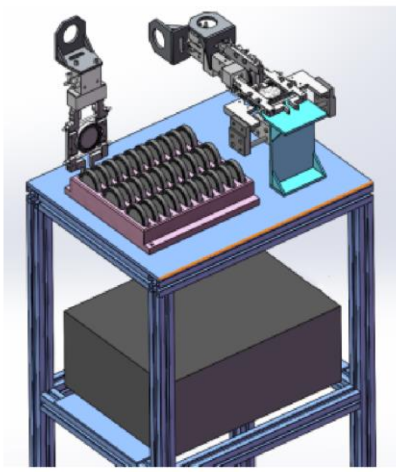

Figure 8: Material placement system

The secondary positioning device is shown in figure 9. The SMC large-stroke MHL2-20D1 translation-cylinder is adopted as the secondary positioning unit. Secondary position correction can be made for different workpiece products to improve the flexibility of equipment. The robot gripper grabs the hardness block and places it on the platform of the secondary positioning device. The clamp of the secondary positioning device clamps the hardness block to measure the shape and size of the hardness block. At the same time, when the position of the hardness block is deviated, the centre of gravity of the hardness block can be adjusted by clamping to compensate the position error of the hardness block. After measuring the shape and size of the hardness block and compensating the position, the hardness block shall be pressed according to the set product specification and path.

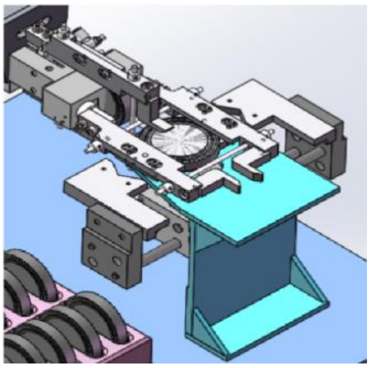

Figure 9: Secondary positioning device

2.2.3 Interactive control system

The principle block diagram of the computer control system is shown in Figure 10. It is mainly used to control the reset and automatic variable load of weights, the automatic loading and unloading of test force, the automatic measurement of indentation depth, the automatic processing and operation of data, and the automatic determination of qualified and unqualified results. After the computer control system receives the reset signal, the control motor drives the loading mechanism to reset. During this period, the control system constantly detects the on-off state of the reset state line. When it reaches the reset state, the motor stops moving. According to the selected test force, the control system drives the corresponding weight corner mechanism to complete the automatic transformation of loading weights, and then the control system waits for the next command. After the control system receives the command to start the test, the computer automatically completes the loading, delay, main load loading, delay, main load unloading and initial load unloading of the initial load test force through controlling the motor with power loading mechanism. During this period, the control system collects the force sensor signal and the spindle running position and state signal in real time, controls the different speed of the motor and determines the reading time of the indentation depth of Rockwell hardness according to the different state of the signal[7]. At the same time, the curve of force value changing with time is plotted. The displacement signals of the laser interferometer are collected at two moments after the initial test force loading and the main test force unloading to complete the calculation of parameters such as Rockwell hardness. At the same time, the curve of the indentation depth of Rockwell hardness changing with time is drawn.

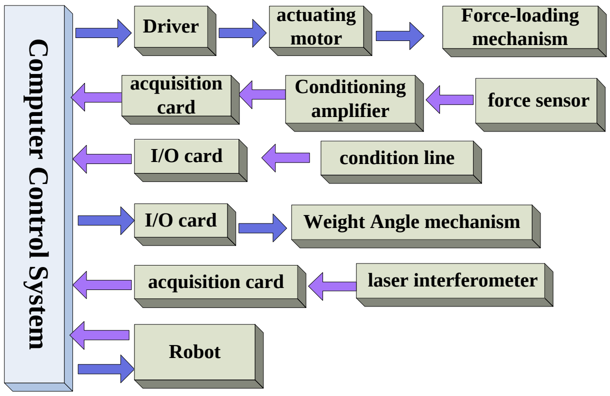

Figure 10: Schematic diagram of computer control system

The computer and robot information interaction system requires coordination and cooperation in order to realize automatic grasping of hardness block, automatic pressing the indentation point, measurement and determination under the overall control of the computer. Its interaction flow and interaction signals are shown in Figure 11. The interaction system between computer and robot communicates by means of six pulse signals, as shown in the figure, the first, third, fourth and fifth signals are the impulse signals sent by computer to robot, and the second and sixth signals are the impulse signals fed back by robot to computer, which are controlled by computer through PCI3232I/O card.

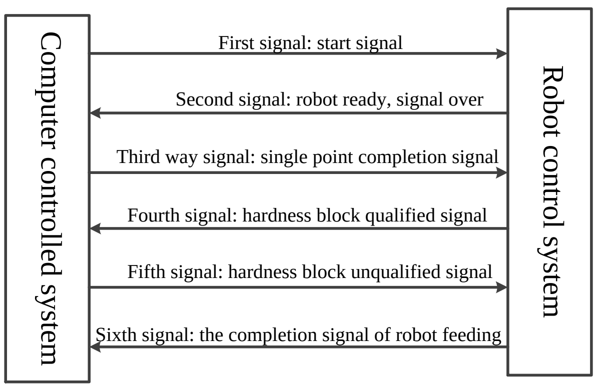

Figure 11: Interaction signals between computer and robot

2.3 Research Results

This paper has realized the development of an unmanned precision measurement and calibration device for Rockwell hardness, as shown in Figure 12. The research results have the following characteristics:

1) The precision measurement of Rockwell hardness is realized by using intelligent laser standard device to calibrate the hardness value;

2) Using robot hands instead of human hands, which realizes the automatic grasping and sampling of multi-sample hardness blocks;

3) By using qualified material plate and unqualified material plate, the automatic determination and classification of the calibration results of the calibrated hardness block is realized;

4) The device realizes automatic unmanned measurement calibration of Rockwell hardness throughout the test process;

5) Different experimental sample blocks (round blocks and squares) can be measured, and different dot trajectories can be set.

Figure12: Unmanned precision measurement and calibration device for Rockwell hardness

3. EXPERIMENTAL RESULTS AND ANALYSIS

Rockwell hardness unmanned precision metering calibration device realized automatic metering calibration of 42 hardness blocks at a time. 12 hardness blocks with different hardness values were selected for the test. According to ISO6508 Metallic materials-Rockwell hardness test[8], the original manual method was used to manually measure 6 points of each hardness block. Finally, the standard value and uniformity of the hardness block were obtained. After the measurement was completed, the 12 hardness blocks were put into the material placement system. Set measuring scale and dot track to realize the automatic measurement of hardness block. Similarly, each hardness block was measured for 6 times (the first point is excluded) to obtain the hardness value and uniformity measured automatically. The test data were shown in table 2.

In Table 2, the standard value and the standard uniformity were the measured results of manual sample placement, while the test value and the test uniformity were the measured results of unmanned automatic sample placement. The hardness value deviation and the uniformity deviation were respectively compared. It could be seen from table 2 that the deviation of uniformity between automatic measurement and manual measurement was 0.1HRC at most. It proved that the unmanned calibration device has good repeatability and stability, and could reflect the uniformity of hardness block objectively and truly. The maximum deviation between the hardness value measured automatically and the standard value measured manually was 0.1HRC. It was shown that the unmanned calibration device of Rockwell hardness in this paper has high accuracy, so it could completely replace the standard device of manual measurement.

Table 2: Test record results

Hardness block number	Standard values（HRC）	Standard value uniformity (HRC)	Test value (HRC)	Test value uniformity (HRC)	Hardness value deviation（HRC）	Uniformity deviation (HRC)
R2007-101	61.2	0.1	61.1	0.2	-0.1	0.1
R2007-102	61.0	0.1	61.1	0.1	0.1	0.0
R2007-103	60.5	0.2	60.6	0.3	0.1	0.1
R2007-104	61.3	0.2	61.3	0.1	0.0	-0.1
R2007-105	63.1	0.2	63.2	0.2	0.1	0.0
R2007-106	63.5	0.2	63.6	0.3	0.1	0.1
R2007-107	40.8	0.2	40.8	0.3	0.0	0.1
R2007-108	41.8	0.3	41.7	0.4	-0.1	0.1
R2007-109	44.5	0.4	44.4	0.5	-0.1	0.1
R2007-110	41.9	0.4	41.8	0.4	-0.1	0.0
R2007-111	43.6	0.2	43.5	0.3	-0.1	0.1
R2007-112	42.0	0.5	42.0	0.5	0.0	0.0

The completion of Rockwell hardness unmanned precision measurement calibration device truly realized the unmanned precision measurement calibration of Rockwell hardness, which has the following significance:

1) Breakthrough in system control: It could automatically filter whether the hardness block was qualified or not, and automatically saved file parameters, etc. It could be continuously used for five hours without human intervention, and truly realized the unmanned automatic calibration of hardness blocks. It completely liberated the human resources and greatly improved the work efficiency;

2) Breakthrough in calibration specification: The pressure position changed of a single hardness block in Rockwell hardness automatic metering and calibration device was completed automatically by the robot hand through the set program. The position of the dot was completely in accordance with the spiral of Archimedes, and the position of the marking point of the hardness block was further standardized；

3) During the calibration process, the system would automatically screen the hardness block for uniformity. The whole working procedure was orderly, the operation flow was simple and standard, and the device runed stably and reliably

The device perfectly combined the precision measurement technology with the intelligent measurement technology. It has not only achieved a major breakthrough in hardness measurement, but also provided a good direction for the development and development of other hardness precision measurement calibration.

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