International Journal of Frontiers in Engineering Technology
ISSN 2706-655X Vol. 7, Issue 1: 1-8, DOI: 10.25236/IJFET.2025.070101

Automatic Inspection System for Brake Beams Based on Linear Laser Scanning

Haoran Li[a], Boyu Tian[b], Jia Yao[c,*], Wei Lu[d]

School of Mechanical and Electrical Engineering, Guilin University of Electronic Technology, Guilin, Guangxi, 541004, China
[a]3290449814@qq.com, [b]2480998148@qq.com, [c]13845459536@163.com, [d]lujunqi2001@163.com
[*]Corresponding author

Abstract: *The brake beam of railway vehicles represents a mass-produced, structurally intricate, and indispensable component. In pursuit of full automation and digitalization in brake beam inspection, we have devised an automatic brake beam inspection system leveraging linear laser scanning technology. This system possesses the capability to swiftly and autonomously identify and locate faults on brake beams, while conducting comprehensive inspections of various parameters. By conducting in-depth data analysis of the measurement results, the system delivers precise and reliable inspection outcomes, thereby guaranteeing the quality and safety of brake beams. The application of this technology signifies a remarkable enhancement in both the efficiency and accuracy of brake beam inspections, ultimately contributing to the overall improvement in the safety and reliability of railway transportation systems. This advancement not only streamlines the inspection process but also ensures a higher standard of safety for railway operations.*

Keywords: *Linear Laser Scanning; Brake Beam Parts; Full-Dimensional Inspection; Point Cloud Data; Feature Extraction*

1. Introduction

With the continuous development of the transportation industry and the increasing requirements for braking system safety, automatic inspection devices for brake beams play a significant role in vehicle production and maintenance. Linear laser scanning is an advanced dimensional inspection technology with higher precision and efficiency compared to other dimensional inspection technologies. By rapidly scanning the surface of an object with a laser beam, linear laser scanning reduces the impact of human error and mechanical vibration, improving the reliability and accuracy of measurement results. Linear laser scanning is efficient, capable of acquiring a large amount of data at one time and rapidly generating 3D point clouds or models, significantly enhancing measurement and production efficiency. Overall, linear laser scanning technology has broad application prospects in the field of dimensional inspection and will continuously drive the development and progress of related industries[1].

2. Design of the Inspection System

2.1 Design of the Inspection Platform

The inspection platform designed in this project includes a data acquisition module, a part rotation module, a part movement module, and a controller. The structural schematic diagram is shown in Figure 1: It mainly consists of a transmission device, a rotating robotic arm, a lifting device, a linear laser profiler, and a conveyor belt. The specific positional relationships of the various components of the inspection platform are as follows: The lifting device is installed vertically and fixed to the platform support through a connecting plate; the linear laser profiler is installed at a certain angle to the lifting device and fixed to it through bolts. The linear laser profiler can achieve reciprocating motion in the vertical direction through the lifting device, and the direction of laser emission is perpendicular to the movement direction of the brake beam to be measured. The rotating robotic arm is composed of multiple parts that can achieve XY-direction as well as height and angle adjustments, allowing it to fix and rotate the brake beam to be measured. The transmission device is installed on one side of the platform support to provide power for the conveyor belt, which transports the brake beam to be measured within the effective measurement range of the linear laser, achieving precise control of the translation and rotation angles of the brake beam to be measured. During specific measurements, the test piece to be measured is fixed on the conveyor belt, and power is provided to the conveyor belt through the transmission device to achieve a streamlined transmission of the brake beam to be measured. The forward triangular surface is aligned with the direction of the laser line emitted by the linear laser profiler, and the controller controls the vertical movement of the linear laser profiler to achieve scanning and acquisition of the test piece data. Analysis of the collected data can solve the measurement of shaft length parameters, aperture characteristic parameters, and oblique angle parameters[2]. By changing the position of the part and scanning the lateral rectangular surface, the brake beam width parameter can be calculated.

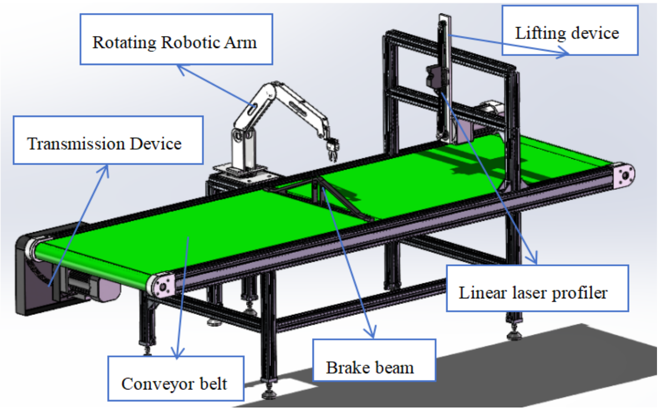


Figure 1: Structural Schematic Diagram of the Inspection Platform

2.2 Design of the Hardware System

A synchronous conveyor belt is set up for transmission, and a motor and combined speed regulator is set up on the transmission platform to adjust and control the transport speed of the conveyor belt. It mainly consists of chains, gears, motors, and speed regulators. The fixed brake beam will be transported to the inspection point with the conveyor belt, achieving streamlined integrated measurement of the brake beam to be measured. The structure is shown in Figure 2[3].

The transmission power is provided by the engine driving the chain transmission; the chain transmission drives the conveyor belt. The principle of chain transmission is mainly based on the meshing action between the sprocket and the chain to achieve the transfer of power and motion. Specifically, the chain is composed of multiple links and pins, and each link has a cylindrical tooth. When the driving sprocket rotates, the teeth on the chain mesh with the tooth grooves of the sprocket, transferring power from one sprocket to another through friction. The combined speed regulator is fixed with the motor at the front end of the transmission platform.

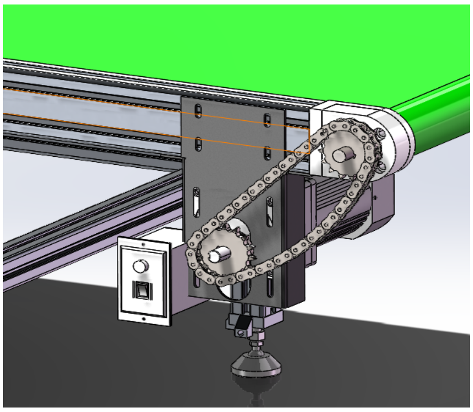


Figure 2: Transmission Device

In the gear chain transmission system, when the motor power of the main gear (180W), gear diameter (60mm), and center distance (200mm) are known, the relevant torque and power transmitted to the secondary gear can be calculated. The following are some key calculation formulas and steps:

In this design, the diameters of the main gear and the auxiliary gear are the same, resulting in a transmission ratio of 1. The chain drive efficiency is 0.93. The input power is 200W (note: there was a discrepancy between the initial mention of 180W and the later mention of 200W for the motor power; here, I'm using 200W as per your later specification). The rotational speed of the motor is 1000 rpm [4].

$$P_{\mathrm{y}} = P_x \times \eta \tag{1}$$

$$T_{\mathrm{y}} = T_x \tag{2}$$

$$T_{\mathrm{y}} = 2\Pi \times N_{\mathrm{x}} \times t \times P_x \tag{3}$$

P_y -Power output of the auxiliary gear, W

P_x -Power of the main gear motor, W

η -Efficiency of the chain

T_x -Input torque, Nm

T_{y} -Output torque, Nm

N_{x} -Rotation speed of the main gear, rpm

t -Time, s

P_y =200W*0.93=186W

T_{y} =2*3.14*1000*60*200≈1.91Nm

The main core components of the linear laser profiler are a CMOS camera and a laser emitter. The CMOS camera mainly captures images of the laser line emitted by the laser emitter onto the surface of the part to be measured. The laser is emitted onto the surface of the object to be measured. Figure 3 shows the imaging schematic diagram of the linear laser profiler.

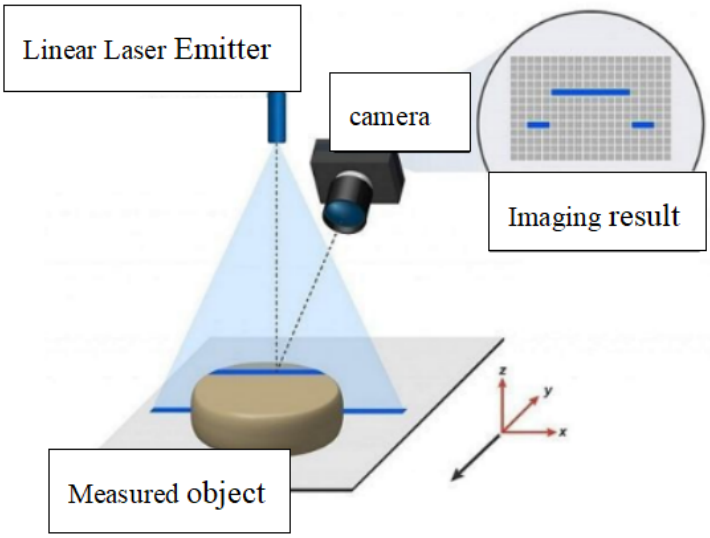


Figure 3: Imaging Schematic Diagram of the Linear Laser Profiler

According to the overall layout plan of the vision system, a single-axis linear motor is selected as the power source to drive the linear laser profiler for scanning motion. To ensure stable and uniform scanning of the linear laser profiler and reliable and valid point cloud data acquisition, a single-axis linear motor with an integrated grating ruler is selected. The motor is driven by electromagnetic force, and the built-in grating ruler displacement sensor provides position and speed feedback, exhibiting excellent linearity and good speed control performance. The linear motor selected here is the HIWIN-SSA single-axis linear motor from Silver. The motor is of the iron-core type, equipped with a grating ruler sensor with a precision of 1 μm, a repeatability of ±3 μm, an effective stroke of 470 mm, a carriage width of 14 mm, a maximum acceleration of 10G, and a vertical installation method[5]. The control modules are the linear motor driver and the linear laser profiler controller, with dedicated cables connecting the motor, sensor, and controller[6].

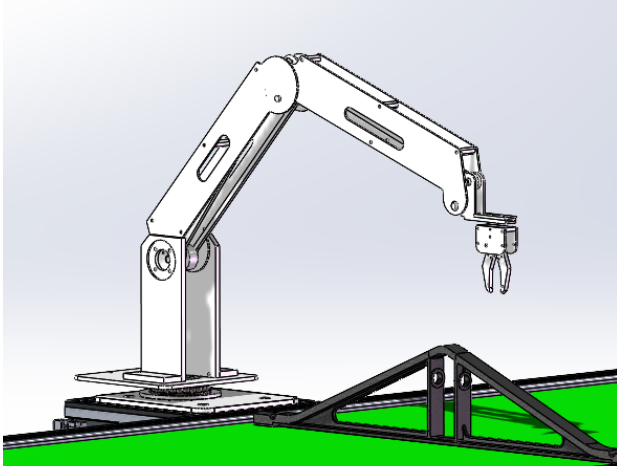


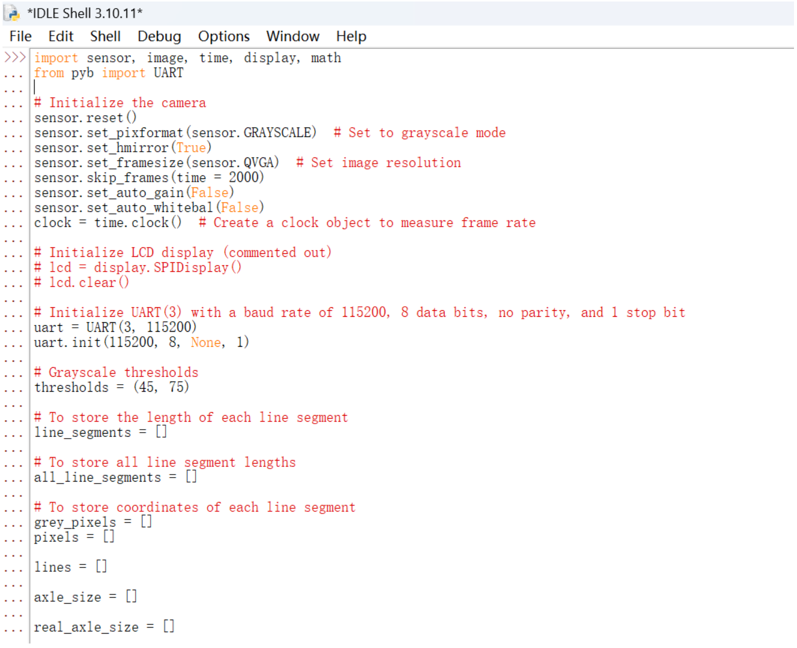
Figure 4: Rotatingobotic Arm

Figure 4 shows the rotating robotic arm, which is composed of unidirectional displacement devices in multiple directions and one angle conversion platform, allowing changes in the angle of the brake beam to be measured. After selecting the above hardware, the final experimental platform built is shown in Figure 4: The rotating robotic arm specifically consists of a base at the bottom, moving parts and joints, a core arm, an end effector, and sensors. The control system of the robotic arm can receive precise instructions and data, control the movement of the joints and the actions of the end effector, clamp the brake beam through the end effector, and realize the rotation and displacement of the brake beam through the rotation of the joints and the movement of the arm, enabling the linear laser profiler to comprehensively scan the entire brake beam[7].

2.3 Software System

The software component of this inspection system is based on the STM32F103C8T6 microcontroller and the OpenMV framework, leveraging a joint development approach using both C language and Python. The STM32F103C8T6 controls the movement of the stepper motor and the activation of the line laser scanner, while OpenMV is utilized to recognize the line laser and calculate lengths. This enables the driving control of the stepper motor and the mobile scanning of the line laser. The measurement system needs to collect point cloud data of the axial surface contour. Specifically, upon switching on the power, the stepper motor, line laser scanner, and OpenMV enter standby mode. The communication port is connected to the control terminal, and the motor moves to a preset position. An instruction is then given to run the scanning program, with the program code shown in Figure 5. The stepper motor drives the line laser scanner to perform scanning movements, and the collected contour data is processed using an actual scale for calculation. The results are displayed and stored on the control interface. Once data collection is complete, the stepper motor executes a homing movement, returning to the set coordinate zero point[8].

The main function of the line laser vision measurement system is to collect surface contour data of the part to be measured, and the collected data is stored in the form of point cloud sequences. By activating the stepper motor and connecting the line laser profiler, points are outputted, and the part to be measured is laser-scanned and labeled. The transformation matrix obtained from the labeling is imported into the collected point cloud model for coordinate transformation. Then, the point cloud coordinates are sorted, and point cloud features are filtered according to the coordinate data to obtain the point cloud to be measured for feature extraction and calculation. Finally, the measurement values are outputted to realize the dimensional measurement of the part[9].



```
import sensor, image, time, display, math
from pyb import UART

# Initialize the camera
sensor.reset()
sensor.set_pixformat(sensor.GRAYSCALE)  # Set to grayscale mode
sensor.set_hmirror(True)
sensor.set_framesize(sensor.QVGA)  # Set image resolution
sensor.skip_frames(time = 2000)
sensor.set_auto_gain(False)
sensor.set_auto_whitebal(False)
clock = time.clock()  # Create a clock object to measure frame rate

# Initialize LCD display (commented out)
# lcd = display.SPIDisplay()
# lcd.clear()

# Initialize UART(3) with a baud rate of 115200, 8 data bits, no parity, and 1 stop bit
uart = UART(3, 115200)
uart.init(115200, 8, None, 1)

# Grayscale thresholds
thresholds = (45, 75)

# To store the length of each line segment
line_segments = []

# To store all line segment lengths
all_line_segments = []

# To store coordinates of each line segment
grey_pixels = []
pixels = []

lines = []

axle_size = []

real_axle_size = []
```

Figure 5: Partial Code of OpenMV

3. Data Acquisition and Processing of Test Pieces

3.1 Data Acquisition of Test Pieces

The test piece is installed in the detection system as shown in Figure 6, with its axis vertically upward and the large end at the bottom.

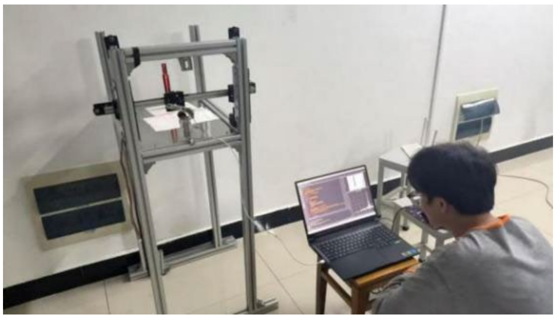
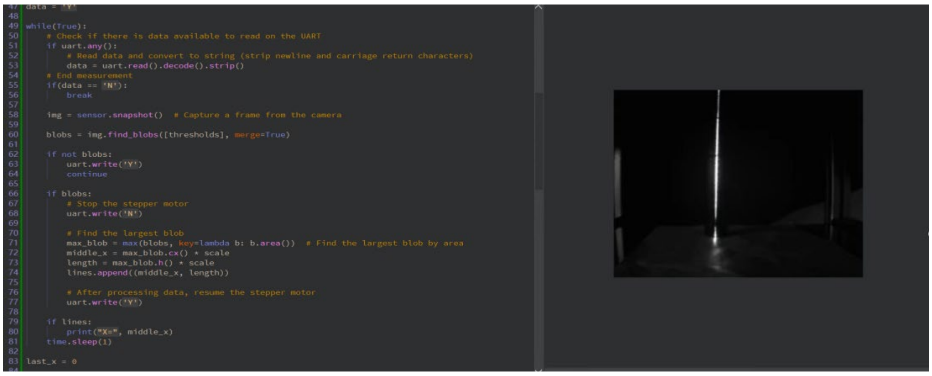


Figure 6: Test Piece Inspection Installation Diagram

After installing the test specimen on the inspection platform, a laser scanning-vision detection system is utilized to collect point cloud data of the test specimen. A single local scan is conducted, followed by the correction of the point cloud data. The correction process is illustrated in Figure 7.



```
data = 'Y'

while(True):
    # Check if there is data available to read on the UART
    if uart.any():
        # Read data and convert to string (strip newline and carriage return characters)
        data = uart.read().decode().strip()
    # End measurement
    if(data == 'N'):
        break

    img = sensor.snapshot()  # Capture a frame from the camera

    blobs = img.find_blobs([thresholds], merge=True)

    if not blobs:
        uart.write('Y')
        continue

    if blobs:
        # Stop the stepper motor
        uart.write('N')

        # Find the largest blob
        max_blob = max(blobs, key=lambda b: b.area())  # Find the largest blob by area
        middle_x = max_blob.cx() * scale
        length = max_blob.h() * scale
        lines.append((middle_x, length))

        # After processing data, resume the stepper motor
        uart.write('Y')

    if lines:
        print("X=", middle_x)
    time.sleep(1)

last_x = 0
```

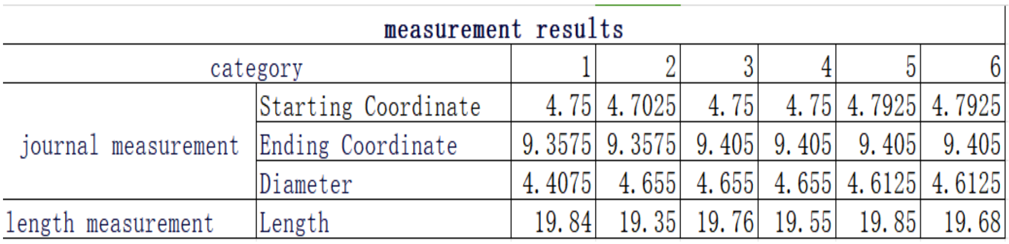
Figure 7: Point Cloud Data of Test Piece

The preprocessed point cloud data of the test piece is used for feature extraction. Firstly, different features need to be segmented. Then, the RANSAC algorithm is utilized to process the segmented features. For the feature extraction of the point cloud data of the test piece studied in this paper, the core lies in the fitting of planes and cylindrical surfaces. Vectors are obtained from the fitted data, and then data calculations are performed to obtain feature parameters. The RANSAC algorithm draws samples from the original data based on randomness and hypothesis, simulates approximate results, and then judges the accuracy of the sampled data. It has strong applicability and stability[10].

3.2 Measurement of Test Piece Shaft Diameter

Based on the point cloud model of the test piece after cylindrical fitting, the shaft diameter values of each shaft segment can be obtained. Data collection and measurement were conducted on the test piece through six experiments, with a preset error tolerance of 5%. The obtained shaft diameter measurement data is shown in Table 1.

Table 1: Shaft Diameter Measurement Data (mm)



measurement results							
category		1	2	3	4	5	6
journal measurement	Starting Coordinate	4.75	4.7025	4.75	4.75	4.7925	4.7925
	Ending Coordinate	9.3575	9.3575	9.405	9.405	9.405	9.405
	Diameter	4.4075	4.655	4.655	4.655	4.6125	4.6125
length measurement	Length	19.84	19.35	19.76	19.55	19.85	19.68

Data Analysis Report

Analysis is based on the six measurement results of a certain component of a train brake beam. The measurement data includes the starting coordinate (diameter), the ending coordinate and diameter of the journal measurement, as well as the length measurement[11].

Analysis of Journal Measurement Diameter:

Mean: $\overline{Y}$ =4.635417.

Variance: S^2 =0.000554.

Absolute error: $\delta = 0.0235$

Error range: 4.635417±0.0235, approximately 4.61~4.66.

Relative error:

$$\begin{aligned} \varepsilon &= \frac{\delta}{\overline{Y}} \times 100\% \\ &= \frac{0.0235}{4.635417} \times 100\% \\ &\approx 0.51\% \end{aligned} \tag{4}$$

The mean journal diameter measurement is approximately 4.64, with a standard deviation of 0.0235. The error range falls between 4.61 and 4.66, indicating high stability. The relative error for the journal diameter measurement is approximately 0.51%, which is below the preset error tolerance of 2%. Therefore, these measurement results are deemed satisfactory, exhibiting high accuracy and reliability.

Analysis of Length Measurement:

Mean: $\overline{Z}$ =19.646667.

Variance: S^2 =0.067575.

Absolute error: $\delta = 0.0235$

Error range: 19.646667±0.26, approximately 19.39~19.90.

Relative error:

$$\begin{aligned}\varepsilon &= \frac{\delta}{\overline{Z}} \times 100\% \\ &= \frac{0.26}{19.646667} \times 100\% \\ &\approx 1.32\%\end{aligned} \tag{5}$$

The mean length measurement is approximately 19.65, with a relatively larger standard deviation of 0.26. The error range spans from 19.39 to 19.90, suggesting some variability in the length measurements. However, the relative error for the length measurement is approximately 1.32%, which is also below the preset error tolerance of 2%. Therefore, these measurement results are considered satisfactory, demonstrating high accuracy and reliability despite the slight variability[12].

4. Conclusion

The brake beam automatic detection system designed in this project, based on linear laser scanning technology, is capable of quickly and automatically identifying and locating faults on the brake beam, as well as comprehensively detecting its various parameters. Through the analysis of six measurement results of a certain component of a train brake beam, we have obtained data such as the mean value, variance, error range, and relative error for each measurement. This proves that the system can provide accurate and reliable detection results. We believe that this brake beam automatic detection system based on linear laser scanning technology will gain wider application and promotion after further development and improvement.

Acknowledgement

This work was supported by the National Level College Students' Innovation and Entrepreneurship Training Program (202410595056).

References

[1] Cai Yuchen, Dong Zhixu, Yang Heran, et al. Noise Reduction Processing Method for Thread Profile Data Based on Laser Measurement [J]. Mechanical Engineering & Automation, 2024, (06): 4-6.

[2] Cai Wanyuan, Shen Bin, Li Zhenyu, et al. Pavement Evenness Process Detection Method Based on Line Laser [J]. Laser & Optoelectronics Progress, 2024, 61(20): 155-163.

[3] Ren Shuai, Shi Jiangang, Lv Junliang. Characteristic Analysis and Experiment of Cavitation Jet Nozzle for Rust Removal Machine of Brake Beam End Shaft [J]. Mechanical & Electrical Engineering Technology, 2024, 53(07): 296-301.

[4] Yan Tingliang. Research on Automatic Detection Method for Profile Accuracy of Turnout Rails Based on Line Laser [D]. Xi'an University of Technology, 2024. DOI: 10.27398/d.cnki.gxalu. 2024. 001082.

[5] Liu Jiahao. Research on Conveyor Belt Tear Detection Method Based on Line Laser Excited Thermography [D]. Nanchang University, 2024. DOI: 10.27232/d.cnki.gnchu.2024.001257.

[6] Luan Feng, Zhao Jun, Liu Yu, et al. Design of Industrial 3D Vision Inspection System for Brake Beam Maintenance [J]. Automation & Instrumentation, 2024, (05): 182-185+190. DOI: 10.14016/j.cnki. 1001-9227.2024.05.182.

[7] Wang Yang. Research on Measurement Method of Shaft Parts Based on Laser Scanning Technology [D]. North University of China, 2023. DOI: 10.27470/d.cnki.ghbgc.2023.001469.

[8] Ye Lilin. Research on Railway Platform Gauge Measurement Technology Based on Line Laser Sensor [D]. Nanchang University, 2023. DOI: 10.27232/d.cnki.gnchu.2023.003804.

[9] Yu Chen. Online Detection System for Veneer Depth Defects Based on Line Laser Scanning Technology [D]. University of Jinan, 2023. DOI: 10.27166/d.cnki.gsdcc.2023.000509.

[10] Wang Xinrong. Realization of Dimensional Measurement Technology for Irregular Shaft Parts Based on Line Laser Scanning [D]. North University of China, 2022. DOI: 10.27470/d.cnki.ghbgc. 2022.001296.

[11] Su Zhizong. Automatic Detection of Railway Freight Car Brake Beam, Automatic Derusting and Flaw Detection of Roller Shaft, and Information Transmission System [C]. Proceedings of the Ninth Session of the Fifth Youth Academic Annual Meeting of China Association for Science and Technology. 2004: 5.

[12] Zhao Jinli, Li Hua, Zhao Jianming, et al. Development of Automatic Inspection Machine for Brake Beam of Railway Freight Cars [J]. Railway Locomotive & Car, 2003, (05): 59-61.