On-line detection device for high temperature forgings based on laser triangulation

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Abstract. This paper takes the online detection equipment of high temperature forgings in the forging environment as the research goal, and uses laser triangulation to perform 3D point cloud imaging of high temperature forgings, and then conducts online detection of the defects, temperature, position, size and other parameters of the forgings. Real-time information feedback of measurement results, and timely adjustment of forging equipment and improvement of production process routes based on the feedback results, thereby effectively improving forging accuracy and forging efficiency, and reducing the work intensity of workers.

1. Introduction
With the development and progress of science and technology, the inspection requirements of forging products are constantly improving. [1-3] However, in the long-term operation of the forging production line, the robot finger block wear, long-term high-temperature deformation of the claw and other factors all lead to the deviation of the placement position of the robot in the high-speed handling of high-temperature forgings, which greatly reduces the qualified rate of forgings, and even causes damage to the mold or press, which seriously affects the long-term stable operation of the production line. In addition, in the forging production process, the forging will often be stuck to the die. After the punching and trimming process of the forging line, the manual sampling inspection is generally carried out. When the product is unqualified, the production line needs to be stopped manually for inspection and die repair, which will affect the stable operation of the automatic production line and increase the manual workload.

Therefore, the conventional forging inspection methods can not meet the complex inspection requirements and more inspection tasks. With the maturity and improvement of the new generation of optical three-dimensional inspection technology, especially laser triangulation [4-9], the development of non-contact inspection device instead of manual inspection of high-temperature forging will become the inevitable trend of the future development of forging industry, especially the online inspection of forging production line Measuring device will further improve the intelligent level of the production line.

2. Principle of laser triangulation ranging technology
The basic principle of laser triangulation ranging technology is based on the geometric triangle. According to the position of the laser spot that the reflected laser beam hits the surface of the object to be measured, the displacement between the object to be measured and the displacement between the object to be measured and the laser source can be determined by calculation. Laser triangulation ranging
technology is more suitable for short distance precision measurement, and can be applied to robot vision system and other fields.

The spot of direct laser triangulation distance sensor is small and the light intensity is concentrated. When the measured surface moves along the measuring direction, the position of the light spot projected on the measured surface does not change. Especially for the red body surface of high temperature forging, the measurement error caused by laser speckle can be limited in a certain measurement range. Therefore, direct laser triangulation sensor is widely used in engineering.

Single-point laser triangulation measurement is a laser light source to project a beam of light to the surface of the measured object, and then in the other direction through imaging observation of the reflected spot position, so as to calculate the displacement of the object point.[10]

According to the relationship between the incident light and the normal of the measured surface, the measurement system can be divided into two types: direct type and oblique type. The principle of direct laser triangulation is shown in the figure below.

The position of the projected light spot will change. In order to make it a clear image on the photosensitive surface of the detector regardless of the distance, a constant focusing light path needs to be built, and the optical parameters of the system must meet the Scheimpflug condition,

\[
a_0 \tan \alpha = b_0 \tan \beta
\]

Where:

\(A_0\) is the distance from the laser spot at the reference point to the main plane of the object side of the imaging lens;

\(B_0\) is the distance from the spot image to the main plane of the image side of the imaging lens;

\(\alpha\) is the angle between the optical axis of the imaging lens and the normal of the measured surface;

\(\beta\) is the angle between the optical axis of the imaging lens and the CCD photosensitive surface.

If the distance of the position of the measured surface moving in the direction of the laser optical axis is \(y\), and the corresponding distance of the position of the spot image moving on the photosensitive surface of the detector is \(x\), then by using the proportional relationship of each side of the similar triangle, it can be concluded that \(y\) and \(x\) satisfy the following equation:
3. Design of master control system

![Diagram of testing equipment](image)

The hardware structure of the detection equipment is shown in the figure above. The sensor of the detection equipment is fixed on the workbench, and the sensor is driven by the servo motor to complete the scanning of forgings. The detection equipment measures the high-temperature forging mainly through the sensors in the equipment to collect the shape point cloud information and temperature information, and improve the recognition accuracy of forging edge through internal image processing. At the same time, the detection equipment is equipped with communication interface with external equipment, which can transmit the detection results to external automation equipment.

3.1. Camera

Industrial camera is the main sensing equipment for high temperature forging detection. The stability and reliability of the camera is closely related to the image acquisition quality and detection results. In this scheme, a high performance photofocus camera is selected, which can effectively adapt to the forging high temperature radiation environment, and can continue to operate stably in the corresponding scene. In addition, the camera has an independent electronic shutter technology, which can easily adjust the exposure time of the camera, and can achieve very short exposure time to obtain a clear image of the high-speed moving target. The exposure time of the camera can be adjusted dynamically according to the temperature value of the temperature measurement unit.

The device takes the high-temperature forging with the size of 400mm × 400mm as the detection target, and the detection accuracy is 0.2mm. The three-dimensional point cloud model of high-
temperature forging is generated by laser contour scanning, and the x-direction resolution of the camera needs to meet the formula

\[
\text{resolving power} = \frac{\text{FOV}}{\text{check the accuracy}}
\]

Where: FOV is the field of vision, that is, the value is 400mm.

Therefore, the x-direction resolution of the camera should not be less than 2000. According to the resolution index, the model of the camera is photofocus mv1-d2048-3d03, with a resolution of 2048 \times 1088, a pixel value of 2 million, and an effective photosensitive area size of 11.26mm \times 5.98mm.

3.2. Laser source

Laser is a kind of single frequency and highly concentrated energy beam, which has the advantages of good convergence and difficult divergence. It is widely used in three-dimensional object measurement and space mapping. According to the wavelength, the laser can be divided into X-ray laser, ultraviolet laser, visible laser, infrared laser, etc. the visible laser can be divided into blue laser, green laser and red laser, etc.

Because the temperature of high temperature forging is generally in 700 ~ 1300 °C, it is red and hot, and emits a lot of red or infrared radiation light, the wavelength is generally greater than 650nm, which seriously interferes with the laser used for detection, resulting in the increase of detection error. Therefore, in order to reduce the radiation interference light, the wavelength of the selected laser source should be far less than the wavelength of the red light, which is conducive to data acquisition and filtering processing. Although the wavelength of X-ray laser and ultraviolet laser is far less than that of red light, they are not suitable for high temperature forging detection because of their expensive equipment, strong penetration and high radiation risk. The wavelength range of blue laser is generally 400 ~ 473nm, which is also far away from the wavelength of red light, moderate cost and low radiation risk, so they are suitable for high temperature forging detection.

Therefore, the blue laser is used as the detection light source, and the laser model is zlaser zm18 405nm blue laser.

3.3. Filters and lenses

Considering that the high temperature forging emits infrared radiation and the detection light source is blue laser, the 405nm band-pass blue light filter is selected to shield the light except blue laser effectively and improve the detection quality.

The working distance between the camera and the high temperature forging is 500mm ~ 1000mm. According to the following formula, the required lens focal length f can be obtained.

\[
f = \frac{\text{working distance} \times \text{sensitivity size of the camera}}{\text{focal length}}
\]

Where:
- the working distance is 500mm ~ 1000mm,
- the x-direction sensitivity size of the camera is 11.26mm,
- the field size is 400mm.
- the selected lens model is azure-2518m3m,
- focal length is 25mm, and the working distance is 890mm

3.4. Moving module

A set of servo mechanism is designed to drive the camera to scan horizontally, and the image acquisition function of the camera is triggered synchronously through the power IO interface of the camera.
3.5. **Embedded industrial control computer**
An embedded industrial control tablet computer is customized for processing machine vision programs. The processor is Intel i5-8400 and the independent graphics card is nvidia GTX 1660.

3.6. **Other sensors**
Infrared temperature sensor: select the FT series digital infrared temperature sensor, model ft-h40k, range 0 ~ 1350 °C, effective temperature measurement distance 100 ~ 800mm.

3.7. **Single chip microcomputer control board**
A set of MCU control board is designed to collect the internal temperature of the device. Through the collection of temperature, through the control of fan, semiconductor cooling chip and other devices for cooling, to ensure the safe and stable operation of the camera.

3.8. **High temperature protection measures**
Due to the high temperature of metal forgings and strong external thermal radiation, the detection equipment always works in high temperature and high heat environment, which seriously affects the performance of the equipment. In order to ensure the normal and stable operation of the equipment, high temperature shielding layer, heat insulation interlayer, semiconductor refrigeration and radiator, fan, vibration and noise protection device are added to realize the protection and control of temperature and vibration.

4. **Software design**

![Software system architecture](image)

The software system architecture is shown in the figure above. The core control module is a system module based on embedded industrial control computer, which is composed of position detection, temperature detection, size detection, defect detection, quality evaluation module and other functional
modules. It realizes the information interaction between the functional modules and the allocation and transfer of system resources. The information acquisition module collects image information through sensors and sends it to the core Halcon image algorithm module based on Halcon software, using a variety of image processing algorithms to realize the detection of forging parameters and position information.

4.1. Software development platform
The software system of high temperature forging inspection is developed based on the joint programming of Halcon and C#.

Halcon machine vision software is a complete set of standard machine vision algorithm package developed by MVtec company of Germany, which has a widely used machine vision integrated development environment. It saves the product cost and shortens the software development cycle. The flexible architecture of Halcon facilitates the rapid development of machine vision image analysis applications. In the industrial circles of Europe and Japan, it has been recognized as the machine vision software with the best performance. Halcon includes a set of interactive programming interface hddevelop, in which Halcon program code can be directly written, modified and executed, and all variables in the calculation process can be viewed. After the design is completed, C, C++, VB, C#, VB and other program codes can be directly output, which is convenient for the development and application of the later detection system.

C# is an object-oriented advanced programming language released by Microsoft, which runs on.Net framework and.Net core (completely open source, cross platform). It has the advantages of powerful development function and short project development cycle.

Through the joint programming of Halcon and C#, the software system of high temperature forging inspection can be developed quickly, and the purpose of on-line inspection can be realized.

4.2. Software interface and function design
A special standardized equipment software for high temperature forging inspection in forging environment is designed for temperature inspection, position inspection, dimension inspection, defect inspection and quality evaluation. The software interface is shown in the figure below.

![Software Interface](Fig5Software Interface)
(1) Position detection function
The function of position detection is to detect the position of the workpiece taken and placed by the robot, and judge whether there is deviation in the position of the workpiece. There are mainly two kinds.

In the process of long-term operation of the forging production line, the finger block of the robot will be worn, and the claw will be deformed when it is heated for a long time. All the above factors will cause the robot to place the high-temperature forgings at high speed, which will lead to unqualified products and serious damage to the press or die.

The position detection is carried out before the robot takes the workpiece. After the press is pressed down, the position deviation of the ejector sometimes occurs. The position matching function of the vision system can guide the robot to correct the grasping position, reduce the downtime rate and enhance the stability of the whole production line. In addition, the detection device can also judge whether the press forging is finished or not, so that the system can give early warning and repair information.

(2) Dimension detection function
The size detection function is mainly to detect the product size in the trimming and punching unit. According to the 3D scanning results, the detection system compares the 3D point cloud diagram with the product standard diagram to judge whether the product size meets the process requirements and the detection accuracy can reach millimeter level. The forging automation production line system can sort the products according to the judgment results, so as to improve the product qualification rate.

(3) Defect detection function
The defect detection function is mainly based on the vision system to scan and image the high-temperature forging. According to the imaging results of three-dimensional point cloud, it compares with the common shape defects in the forging process, such as insufficient local filling, forging under pressure, forging dislocation and so on, to judge whether the forging has defects and the types of defects. If the defect rate is high, it indicates that there are problems in the production process, because the This function is also helpful to the improvement of forging and technology.

(4) Quality assessment function
The quality evaluation function is based on the 3D vision system to detect the size of forgings, the judgment of forging position, the defect detection of forging surface, and the real-time detection of forging temperature by infrared thermal radiation sensor. It can detect the common shape defects in the forging process, such as insufficient local filling, forging under pressure, forging dislocation and so on, and establish the quality evaluation system of high-temperature forgings Evaluation.

5. Online detection technology and process
In addition to the sensors and devices of the above complete sets of detection equipment, the detection platform needs to be added in the forging production line. Because the main press equipment is large, the working range of a robot often can not meet the layout requirements, that is, a robot can not put the final forging products directly into the trimming machine, so it needs to configure two robots and a transfer platform, so the turntable can be used as the detection platform for forging detection, and the transfer platform needs to do some copy work station, which is conducive to workpiece transfer Positioning in the process. [11-10] the product inspection after trimming press is the same as the product with flash. The specific process flow of detection is shown in the figure below.
A robot RB1 is equipped on the final forging side of the main press to place the workpiece on the detection platform (profiling turntable). After the placement, the servo module is informed to drive the laser scanning mechanism to shape the workpiece contour, and the scanning speed is close to 6S / time. RB2 grabs the detected workpiece from the center turntable and judges after obtaining the detection results. If the detection conditions are met, the next cutting process will be carried out. If the workpiece is not placed on the random inspection slide, it will prompt manual confirmation of the workpiece quality. If there are several forging quality problems in succession, the intermediate frequency furnace will be informed to stop. The robot will transport the last forging and return to its original position, and the whole production line will stop. Manual maintenance of mould and press is required. The process flow of forging inspection in trimming station is similar to that in final forging station.

Due to the rapid beat in the forging process, the cooperation between robots is very compact, and the real-time detection of each piece cannot be achieved. Therefore, the detection platform needs to set multi station cache, and the detection station is only one station in the cache. The transfer detection platform is shown in the figure below.

6. Concluding remarks
The on-line detection device of high temperature forging based on laser triangulation can provide important production information such as position, temperature, size and shape defects of high temperature forging for forging automation production line. Moreover, it can provide the main press with a complete set, effectively protect the press and increase the service life of the die, realize the real-
time accurate detection of various parameters in the forging process, further optimize the forging process of the robot forging production line, and improve the product quality and production efficiency of robot forging.

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