Study on connection quality of assembled cam after hydraulic expanding

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Abstract. The cam is an important part of engine exhaust opening and closing. The assembled cam has completely replaced the traditional integrated cam. In this paper, several common methods for assembly effect detection of assembled cam are summarized, and five methods are analyzed and commented from the aspects of measurement form, data form, destructivity, usage scenario and economy. To measure the contact area and residual stress of the fitting surface with the assembled cam, a suitable method is selected, and the research direction is determined.

1. Introduction
Due to the high manufacturing cost of traditional integrated cam, improving its manufacturing process, improving efficiency and reducing cost, assembled cam has gradually replaced the traditional integrated cam, and is gradually applied in automobile, ship and other engines. Cam works under a certain impact load and dynamic torque, and sufficient connection strength is required between cam and tube. Cam quality directly determines the combustion and dynamic characteristics of engine [1]. Therefore, it is necessary to test the assembled cam. By means of testing, the best assembly parameters can be obtained in the experiment, and the product qualification can also be tested in production.

2. Assembly method of assembled Cam
The connection mode between cam and tube mainly includes welding, bonding, hydraulic expansion, hot charging and key connection, etc. Hydraulic expansion joint has the following advantages: a large initial gap is allowed between tube and cam, and the machining accuracy of mating surface is low; No separate processing keys and key ways, the parts no surface damage and stress concentration; Wide adaptability of materials, easy to realize the connection between different materials, without considering their weld ability and adhesiveness, and the connection process does not need heating, will not affect the material structure performance; Assembled cam can assemble, as a whole part, they are equipped with good consistency and high efficiency. The research on the principle and detection technology of assembly cam plays an important role in automobile industry. The experimental principle of expansion joint of assembled cam is shown in Fig. 1. The specific steps are as follows: place the tube in the middle position inside the cam, fix both ends with sleeve, move the two ends punch with liquid filled hole along the tube, and initially seal both ends of the tube; The liquid is filled into the tube by the external high-pressure liquid system. With the increase of the pressure in the tube, both ends of the pressure head apply axial pressure on the tube at the same time. Under the joint action of the two, the tube produces plastic deformation and fits tightly to the mold cavity. When discharging the pressure and taking out the part, the expansion joint is completed. After unloading pressure, cam
elastic recovery, due to the tube resistance, still retain a part of the residual deformation, thus in the 
cam and tube contact surface to produce greater contact pressure, to achieve the fastening.

3. Connection quality of assembled cam

There are many ways to detect the contact surface of assembled cam. According to different 
measurement forms, we can divide the measurement methods into contact measurement and non-
contact measurement. According to different measurement data forms, we can divide the measurement 
methods into contact area measurement and residual stress measurement. As shown in Fig. 2, is a 
schematic diagram of assembled cam with three-blade equidistant section. Contact measurement and 
non-contact measurement are discussed below.

3.1. Non-contact measurement method

The non-contact measurement method mainly uses penetrating ray or visual detection to detect the 
stress or strain of the measuring parts. The method has various detection forms. For the detection of 
expansion joint effect of assembled cam, a X-ray detection method and a visual detection method are 
introduced as follows.

The x-ray is essentially a kind of electromagnetic wave, which is the same as ultraviolet, infrared 
and visible light, but different light has a certain wavelength range, and different wavelengths have 
different physical properties. When X-rays are irradiated to crystal metal substances, diffraction 
phenomena occur when X-rays are irradiated between metal atoms due to the special atomic 
arangement gap of the metal, which is consistent with the wavelength level of X-rays [2,3]. For 
metals with different internal stresses, their atomic gaps will change accordingly, and different gaps 
will produce different diffraction effects, which are reflected in the diffraction direction and intensity. 
When the crystal material is under the action of stress, there will be corresponding internal strain in the 
crystal material. Therefore, in X-ray diffraction detection, the diffraction normal line will change due 
to the change of the relative distance between the crystals. According to the change of the diffracted 
normal line, and then calibrate, the internal stress and stress direction can be obtained. However, due 
to its high cost, it cannot be widely used in all measurement fields.

As shown in Fig.4 is the assembled cam aura with visual detection principle diagram, a circular 
laser beam is emitted from a laser generator to the tube inner surface, the inner surface of the tube 
forms a ring band, again through industrial camera records ring band, through the computer analysis of 
records of image information, get the 3d coordinates on the inner surface of the tube [4]. The 3d 
coordinates of any point on the inner surface of the object can be obtained by computer processing. 
The accuracy of this measurement method is related to the width of the ring band projected by the 
laser generator. In the actual measurement, the ring band is easy to overlap in the images taken by 
the system twice, so it needs to accurately control the distance of the system movement. Meanwhile, this 
method also has high requirements on the assembly and environment of the measurement system.
3.2. Contact measurement method

The contact measurement methods are various, mainly from the cam surface deformation, the cutting surface measurement of the joint section and other physical quantities to reflect the expansion effect of the expansion cam. Testing the Connection quality of assembled camshaft, a method three-coordinate inspection, a method of speckle dynamic strain measurement and a method of using contact resistance to inspect the contact effect of assembled cam are introduced.

Three coordinate measuring technology is a kind of typical contact measurement technology, the technology is mainly applied to detect the appearance of parts size and position. There is a certain gap in the fitting surface of the assembling cam, can take advantage of the three-coordinate measuring technology to measure, can get the clearance between the cam and tube, and analysis of assembled cam assembly effect. Its principle is fixed in the object to be tested on the position of the three coordinate measuring machine measurement, according to the principle of 3d point for each measurement point on the object to be tested for 3d coordinate, and coordinate data of the processing, can be measured geometric parameters of the parts, calculate the size, shape, size and shape parts of mutual position, measurement accuracy can reach micron level often [5]. As shown in Fig.5, the assembly cam intermediate section A-A is linearly cut to obtain measurement specimens, and then the A-A interface is scanned and measured. In the development of science and technology, the application of cam is more and more extensive, on the one hand is to gradually reduce its cost, on the other hand is to intelligent, precision, high-speed and numerical control direction.

The speckle dynamic strain measurement uses binocular stereo vision to recognize and reprocess the speckle sprayed on the surface of the measuring piece, and mainly applies the digital image processing technology. After the corresponding deformation occurs on the surface of the tested part, the continuous speckle image can be obtained, and the image can be digitized to calculate the strain and deformation characteristics of the surface of the tested part [6]. The measurement technique is especially suitable for the measurement of three-dimensional deformation under static and dynamic loads and the analysis of deformation and strain of the actual components. As shown in Fig.6, it is a schematic diagram of speckle stress measurement of assembled cam. After spraying the surface of the cam with white speckle, install the cam and tube on the hydraulic equipment, and at the same time place two high-speed cameras on the side of the speckle cam. In the process of assembled cam expanding, the expanding period due to expanding the role of the liquid pressure relative displacement in the cam surface speckle, through high-speed cameras around speckle displacement of real-time data, and according to the displacement data to get the corresponding stress data, data easily in the process of the surface of the finished surface strain and expanded joint strain.
Two or more conductor metals have contact resistances on their contact surfaces, and the resistance value of contact resistances may not be fixed, which depends on many factors, such as mechanical contact pressure, contact area, etc. [7]. As shown in Fig. 7, the fitting surface diagram of the assembled cam with three-blade equidistance profile structure is respectively the assembly section diagram and the contact surface microscopic diagram. It can be seen from the diagram that both the cam and the tube have elastic recovery and the contact area is greatly reduced. At the already contacted position, the actual contact area is smaller due to the uneven surface of the material, and the actual contact area of the assembled cam is much smaller than the mating surface of the tube and cam [8,9]. Thus, it can be seen that the actual production of contact resistance is the real contact area of the cam and tube far smaller than its matching surface area.

The contact resistance of the expanded specimen was measured under the condition of controlling the same temperature and surface mass. The contact resistance obtained reflects the comprehensive performance of the contact area and residual stress on the mating surface of the assembled cam, while the contact area and residual stress on the mating surface reflect the expanding effect and bearing capacity of the assembled cam. Contact resistance not only exists in the between the cam and tube, the wire and tube, is also a contact resistance between the cam and connecting wires that affect the size of the contact resistance, in order to rule out the influence of contact between the wire and test pieces of resistance, choosing kelvin four line test method, method principle diagram as shown in Fig. 8 [10,11]. The measurement data is independent of the wire contact resistance, which effectively reduces the error of the measurement principle.

The physical connection diagram of the contact resistance of the assembled cam of the kelvin four-line test is shown in Fig.9. Two wires are connected to each end of the tube. The cam used in the experiment is composed of three parts, when the cam middle position or side position is studied separately, a cam connecting a certain position can be selected for separate study. Several groups of experimental data were obtained by measuring the assembled cam formed by under different working conditions, and the corresponding contact resistance value was calculated by Ohm's law. The residual stress and contact area of the corresponding experimental assembled cam were measured separately by this method, and the corresponding values were obtained, and the resulting contact resistance was calibrated. In the end, this experiment can be established cam contact resistance and residual stress, the relationship between contact area, only need to measure the contact resistance experiment of its kind.
in the future, you can get the corresponding residual stress and the contact area, also can be in the process of cam life experiment measuring contact resistance with the unceasingly, to detect the cam work efficiency.

Fig. 8 Resistance measured by the Kelvin four-wire method

Fig. 9 Is a schematic diagram of four-line test for assembled cam

4. Comparison of five detection methods

As shown in Table 1, the parameters of the five detection methods are compared, mainly including: measurement methods, data form, destructive, usage scenario and economy.

Table 1. The parameters of five detection methods were compared

| Number | Measurement methods          | Contact Type | Data Type    | Destructive | Usage Scenario         | Economy   |
|--------|------------------------------|--------------|--------------|-------------|------------------------|-----------|
| 1      | X-ray diffraction method     | Non-contact  | Stress       | No          | Experiment/production  | Expensive |
| 2      | Halo visual detection        | Non-contact  | Volume       | No          | Experiment/production  | Expensive |
| 3      | Three coordinate measure     | Contact      | Clearance    | Yes         | Experiment             | Expensive |
| 4      | Speckle stress detection     | Contact      | Strain       | No          | Experiment             | General   |
| 5      | Contact resistance method    | Contact      | Resistance   | No          | Experiment/production  | Cheap     |

The X-ray diffraction method is better than the other four detection methods, but it cannot be used in all situations due to the high cost of the measuring equipment. The ring belt detection method has low accuracy, high installation precision and high price. Three coordinate measure has high precision, but the sample needs linear cutting, and the measurement data is cross-section data, which is expensive, which is not conducive to the measurement comprehensiveness and economy. Speckle stress detection can detect the change of the residual stress of the mating surface in the process of expansion, but the cost is relatively expensive and the measured data is single. By contrast, detection of the cam, the contact resistance between the method detecting axle tube under different working conditions and the real contact area between the cam, a real contact area directly affects the assembled cam assembly stiffness, the real contact area of influence of the assembled cam assembly effect, has some advantages such as simple equipment, strong applicability, non-destructive, and good economy.

Table 2. Contact resistance detection scenarios and specific methods of assembled cam

| Usage scenario               | The specific method                                                                 |
|------------------------------|-------------------------------------------------------------------------------------|
| The experimental test        | Effect test of assembled camshaft sample                                          |
| In fatigue test              | Variation of contact area and residual stress of assembled camshaft under load    |
| In fatigue test              | In fatigue test, the variation of contact area and residual stress was studied and analyzed |
| The production practice      | Sampling test product quality                                                      |

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5. Conclusion
This paper introduces the common detection methods of assembled cam, and compares the measurement forms, data forms, destructive, usage scenarios and economy of several mentioned methods. In order to simplify the measuring process, all wire connections can be designed as fixtures to improve the measuring efficiency. The quantitative relationship between equivalent contact resistivity and residual stress and contact area can be established by measuring and analyzing the parameters of the assembled cam under the same conditions as the ambient temperature and surface quality of components.

At present, assembled cam is widely used. In the future, the research direction is still from the following four aspects:
1) In terms of contact form, research on interface contact form of assembled cam assembly;
2) In terms of detection methods, the contact area detection method of cam mating surface is proposed;
3) In the aspect of simulation research, the contact area detection principle was simulated and analyzed;
4) For the detection device, the contact area detection device for the assembly interface of cam was developed.

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