Review and Prospect of Residual Stress Detection

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Abstract

In this paper, the principle and method of testing residual stress are briefly analyzed. The residual stress is a kind of elastic stress [1]. The traditional methods mainly include loss test method and nondestructive testing method; model test method including crack compliance method, nano indentation method, laser ultrasonic method and online real-time detection method [2].

Keywords

Residual stress, Test method.

1. Introdution

In the process of production, processing and processing of materials, due to the uneven plastic deformation in the local area, the residual stress will be produced. The residual stress is generated in the process of material and products in machining or in alloy materials and products of the internal balance in an unstable state of stress, effect of residual stress on the fatigue properties of materials is the most obvious, would seriously reduce the structural strength of material, shorten the fatigue life. At the same time, the material residual stress accumulated will make the formation of cracks on the surface or near the surface of the surface crack, the hidden in the materials and components of near surface defects is often the starting point to break, more subtle and dangerous [3]. Therefore, it is of great significance to measure the residual stress effectively [4].

There are dozens of current methods of measuring the residual stress, according to the structure is destroyed, it can be divided into a loss test method and nondestructive testing method, a loss test method mainly includes: small hole method, ring hole method, heart method, cutting method, denomination method, hardness, indentation, photo elastic coating the blind hole drilling method and measuring method of stress release. Nondestructive testing methods include: X ray method, neutron diffraction method, ultrasonic method, magnetic method, etc. And a new test method: crack compliance method, nano indentation and laser ultrasonic detection method. In this paper, several common methods are briefly analyzed and introduced [5].

2. Residual stress detection method

2.1 Pinhole method

The hole is first attached to the strain gauge measured structure of the measuring points, then the pieceworker with a special tool in the center hole of the strain gauge on a diameter of about 2mm and the depth of holes, the initial stress release, through the determination of resistance change of strain gauge to determine the stress in [6].

2.2 Ring core method

The ring core method is a more sensitive and accurate test method proposed by Milbradt [7]in 1951.The principle is similar to the drilling method, the difference is that the small hole into the inner diameter of 15~150mm, the inner diameter of the size of the ring 25%~150%, as shown in figure 1. The advantage of this method is that the strain range is large, and it is easy to detect. However, this method has a large damage to the parts and should not be used frequently. Therefore, researchers have made a continuous improvement of this method, in the end, Gunner and Hast in 1955 and in the year of 1958 to the direction of the accuracy and comprehensiveness of the perfect and development.

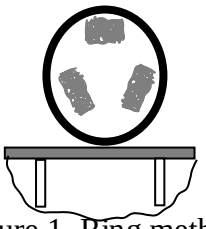

Figure 1. Ring method

2.3 Deep hole method

The deep hole method is a kind of improved testing method which is combined by the drilling method and the ring core method. The first principle is a drilling holes in the parts, accurate measurement of the diameter of the holes [7], and then a hole drilled in the concentric parts of the ring, because the surrounding stress release and the diameter of the holes is changed, the calculated hole stress of the original[8], as shown in figure 2. The biggest characteristic of the deep hole method is that it can measure the residual stress in the inside of the part. In addition, the thickness of the sample is not restricted, such as the weight of a few tons of steel, aluminum castings are to meet the requirements of the measurement. As early as 1978, Zhadanov and Gonchar [8] using this method to measure the welding residual stress of steel. In 1987 Beauey [9] and Procter proposed the use of non-contact capacious strain gauges to measure the diameter of the hole to make the measurement more accurate and effective. In recent years, the research on deep hole method of domestic and foreign scholars have never stopped, which has the outstanding achievement is Smith and his team, he made changes in the use of air probe to measure the diameter of the holes, while the introduction of electrical discharge machining (EDM) technology to complete the ring hole, will eventually be the development of standard test method for measurement of isotropic as a kind of thick section material. With the continuous development of technology, researchers have used this method to test the residual stress of an isotropic materials (integrated composites).

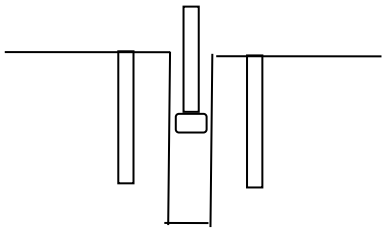

Figure 2. Deep hole method

2.4 Strip method

In 1888, the Ralakoutsky [10] method was used to measure the size and distribution of residual stress along the length of the cylinder. This method is a kind of cutting material along the length of the part to release the stress, and the residual stress is calculated by measuring the strain on the line. It is assumed that: (1) the stress along the thickness direction is negligible; (2) the plastic and thermal strain are not introduced during the cutting process. In practice, however, the stress along the thickness direction is present. Therefore, the smaller the value of the stress in the thickness direction, the more accurate the residual stress value is. In 1998, Scha [11] fer of cutting along the length direction of the material process, will produce axial deformation and bending, correspondingly along the thickness direction will produce residual stress and bending residual stress, and bending residual stress has a linear relationship with the thickness change law. In 2008 Cruise and Gardner draw residual stainless steel film section of relationship between stress and bending residual stress and yield stress of the material through the experiment, the accuracy of measurement of residual stress in a big step forward. Figure 3 shows the principle diagram by cutting method measuring residual stress of steel structure. At present, the residual cutting method is widely used in measuring the structure of carbon steel, stainless steel, alloy Aluminum Alloy stress.

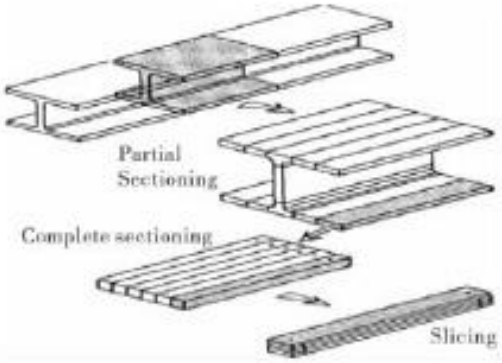

Figure 3. Strip method

2.5 Layer stripping method

Stripping method is often used to determine the simple geometry of the specimen, the test process is quick, only a simple determination of its change in curvature can be calculated residual stress value. The principle is that when a layer of material removal from the residual stress with electronically flat or cylindrical when the residual stress will no longer balance when it re balance will lead to the plate deformation, curvature of plate bending depends on the material layer is removed the original residual stress distribution should be elastic properties and the remaining part of the material. The original residual stress distribution of the plate can be obtained by calculating the curvature of the plate after removing it.

2.6 Hardness method and indentation method

Hardness [12] test is the use of the stress effect of hardness, by comparison method to measure the size of stress, and the hardness indentation method is very similar, the pressure head with some hard cone, caused a small circular pits on the surface of the material to a standard pressure condition, when the residual stress exists on the surface, remove the head, round the pit will change the size or become oval, accurate measurement of dimensional change or ellipse axis, it can be regarded as the residual stresses. Indentation test principle is the so-called pressure into the problem, that is, with a certain geometry of the indent er on the surface of the solid material quasi thermostatic loading, the material into the indentation response. The type and size of residual stresses are determined by the indentation response.

Press in the process generally experienced three stages: the first stage is pressed into the elastic stage in elastic stress state; the second stage is the transitional stage, starting from the material elastic stress state into the plastic stress state, but the plastic deformation area did not reach the free surface and the occurrence of plastic deformation of the material is always the surrounding elastic material constraints; the third stage is the full plastic deformation stage, indentation has begun to yield and produce plastic deformation and plastic flow, the free surface does not exist on the plastic deformation of the elastic constraint. By measuring the amount of displacement and stress caused by stress superposition under local load, it is deduced that the original stress [13].

2.7 Hole drilling method for photo elastic patch

In the component being the residual stress on the testing point of the photo elastic coating in paste, then point drilling, together with the patch together to drill through the residual internal stress components are part of the release, according to the size and direction of the patch graphics in the achromatic release stress strain under the action can be launched within the residual deposit force.

The photo elastic coating method is a variety of measuring borehole stress (dynamic stress, residual stress and static stress and stress concentration) method in the large area of the structure for measuring fertility hole method and other test methods selection of measurement area, and can directly determine the maximum principal stress, tracking the maximum principal stress, has the advantages of full field, intuitive, convenient reading, destructive etc..

2.8 Electrical measurement of blind hole stress release method

Electrical measurement of blind hole stress release method of component failure is small, the end of the test will be Kong Tianping [13], does not affect the use of equipment. The test instrument operation is simple, lightweight, portable field use, has certain sensitivity and accuracy (accurate quantitative), strain measurement technology and drilling operation skills but require testing must have a mature, pay attention to every step, otherwise it will affect the test accuracy. There is also a lack of point by point measurement.

3. Nondestructive residual stress testing method

3.1 X ray method

X - ray diffraction phenomenon by X ray is incident to the material, to determine the strain according to the change of material spacing, and then through the elastic mechanics law by strain calculated stress value, is a kind of method for nondestructive measurement of residual stress on the surface, is still on the stress measurement method most widely and deeply, mature, widely used in various fields of scientific research and industrial production. X - ray method mainly includes X - ray radiography, X - ray diffraction and X-ray stress analyzer. A method of low efficiency and large error, especially in the diffraction lines very diffuse is more prominent, and generally can only measure the stress of small specimen; diffraction method and stress meter method is the main method to test the residual stress, the former is generally applicable to small sample stress measurement, the latter sample size suitable, more suitable for the field test, the most widely used. With monochromatic ray incident on the crystal, such as diffraction angle 2 theta, spacing D, wavelength lambda X ray meet the Prague equation: occurs due to diffraction of metal material by a large number of random grain orientation, always produce diffraction in some favorable grain orientation. When the component is subjected to external stress or internal residual stress, the strain of the crystal plane spacing is different, and the stress is different in different directions. The strain can be determined by measuring the peak displacement, and the stress is calculated according to the elastic mechanics.

X2001X ray stress meter developed by us AST Company and X2002 software system. Figure 4 shows the diffraction geometry of X2001X stress gauge. The stress analyzer adopts a novel Modified PSI Diffraction geometry. 2 A and B position sensitive detectors are installed symmetrically on both sides of the ray, and the diffraction information can be detected, which can shorten the time of X ray stress analysis and improve the accuracy of stress analysis.

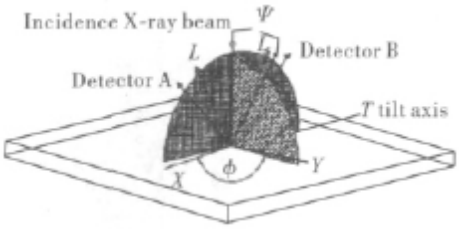

Figure 4. Schematic diagram of Modified psi diffraction

3.2 Neutron diffraction method

Neutron diffraction stress analysis began in 1980s, is a kind of nondestructive measurement of residual stress of the method developed in the past 20 years, and is currently the only available 3D stress distribution method for determination of large volume workpieces. Neutron diffraction is the peak position and intensity of the diffracted beam, can obtain the stress or strain data. The method of neutron diffraction stress measurement is to measure the strain of the lattice in the material, and then calculate the stress. The principle of measuring residual stress is basically the same as that of X ray method, that is, according to the law of Prague, the residual stress is calculated from the elastic strain of the lattice. Figure 5 is a schematic diagram of the principle of stress measurement by neutron diffraction

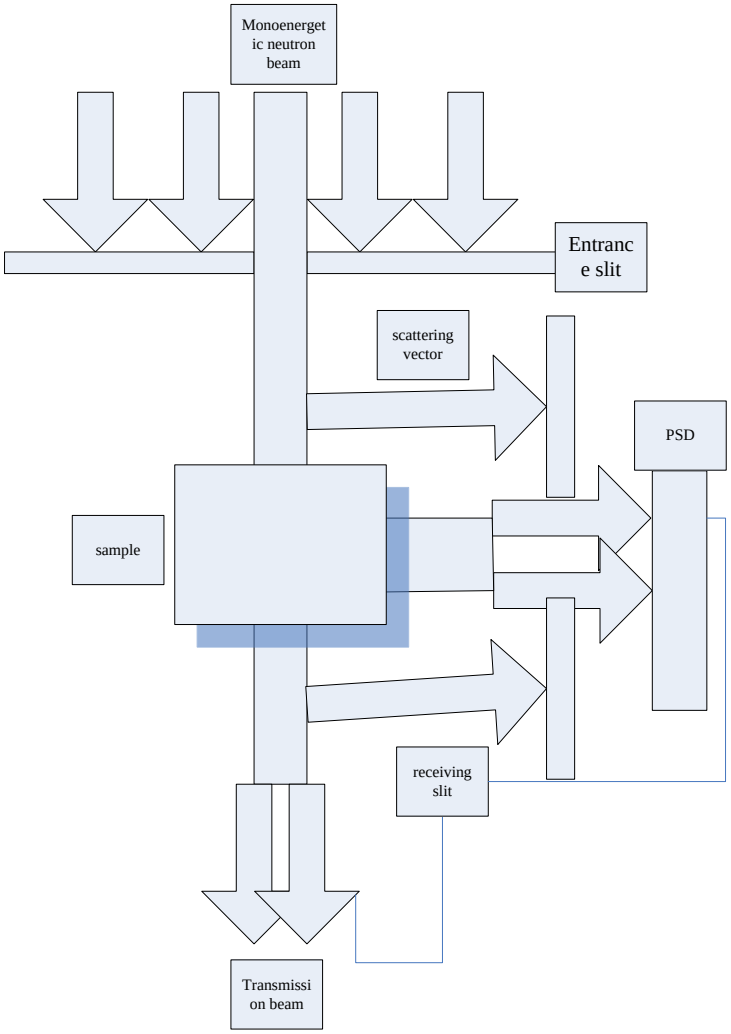

Figure 5. Schematic diagram of stress measurement by neutron diffraction

According to the Prague formula, a differential relation with income after the peak position should be no changes in peak position reference theta force value of 0 samples to obtain the strain of theta delta.

3.3 Ultrasonic measurement

Ultrasonic testing is a method for nondestructive testing of residual stress. It is based on the propagation characteristics of ultrasound in the material, and the average stress of the ultrasonic propagation path is measured by the stress induced infringement effect.

There are two kinds of test solutions, one is using ultrasonic shear wave as a means of detection, the propagation velocity of Shu Zhengjiao [14] polarization shear stress influence, double refraction, two beams of ultrasonic shear waves were measured to evaluate the echo arrival time of material in the internal stress state, the program applies only to material stress; scheme two is the use of surface wave or wave time, direct measurement of acoustic waves in the surface or internal communication, and then based on the relationship between stress and velocity of the acoustic elastic theory to measure stress, the scheme can measure stress surface or internal, so it has gradually become the mainstream of research. In the process of measuring residual stress by ultrasonic method, the measured stress is the average value of the ultrasonic propagation path. The ultrasonic stress measurement in solid medium is mostly based on the correlation between stress and velocity as the foundation, namely ultrasonic directly through the measured medium, the measured medium itself as the sensitive element, the sound velocity changes reflect the stress of solid. Available in solid velocity, in which K is the elastic modulus, density P. When the ultrasonic wave propagates through a solid under stress, the stress has two effects on its velocity. The elastic modulus and the density change with the strain, usually both of these changes are relatively small, up to only about 0.1%. The experimental results

show that the velocity of sound varies with the change of force is in a good linear relationship. The use of ultrasonic stress measurement is based on the acoustic elastic effect, that is, the strain caused by the change of ultrasonic velocity. According to the theory of acoustic elasticity, as long as the deformation is within the elastic range of the material, the velocity and stress change linearly.

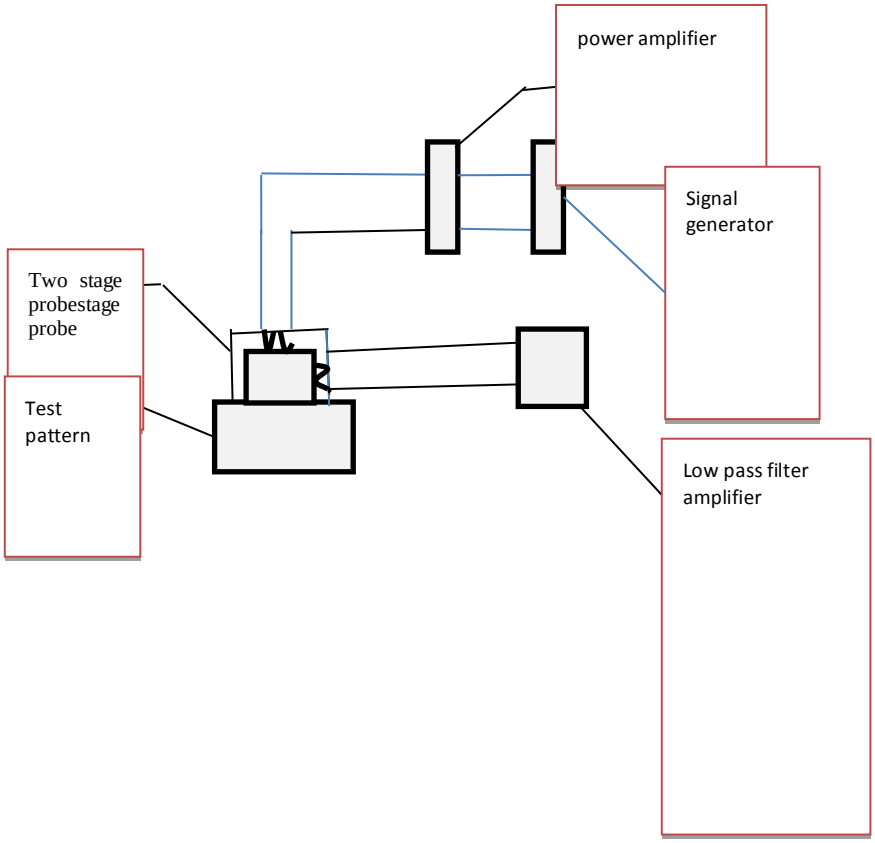

Figure 6. The magnetic stress principle diagram

3.4 Magnetic method

Magnetic method is a new method to measure the residual stress. It is convenient, rapid and accurate. The magnetic stress method are mainly used Barkhausen [16] method, the inverse electromagnetic effect method, the magnetic memory method of MMM (Electromagnetically), stress induced magnetic misanthropy method SMA (Stress in electromagnetically) and MAPS (Magnetic misanthropy and permeability system) etc.

The magnetic stress method is the inverse effect or Valarie effect based on electromagnetic effect, by investigating the changes of magnetic properties of material stress situation. At present, there are two kinds of magnetic methods: magnetic noise method and magnetic strain method. Magnetic noise method is a ferromagnetic material in an alternating magnetic field under the action of magnetic domain walls occur discontinuous jumps dramatically, thus releasing elastic stress - strain wave, this phenomenon is called magnetic noise, also known as the Magnetic Barkhausen [15] noise (BN). Changes of stress and micro structure and defects related to size and materials of the BN signal, so some people to detect the stress, micro structure and defects in the size of a pulse voltage signal generated in the induction coil detection by measuring BN. In the measurement of BN information hours, it is necessary to distinguish the impact of various factors. In our country, the magnetic method for measuring residual stress is more magnetic strain method. Its principle is based on the ferromagnetic material (such as low carbon steel etc.) the electromagnetic effect of ferromagnetic materials, which will occur in the size change of magnetization; in turn magnet under stress of the magnetization (magnetic strength and permeability etc.) can also be changed, influenced by stress, permeability of ferromagnetic materials the magnetization of the macro parameters, this influence is attributed to the domain in the magnetic moment should occur coupling stress field and magnetic

field inside and outside under the steering and domain wall displacement. The general structure of steel, in no stress, can be considered as isotropic body, when the elastic deformation is generated when the magnetic misanthropy, the permeability of each direction will be changed, the magnetic stress method is to reflect the change of stress by measuring the change of permeability, permeability changes through the sensor to reflect the impedance change of magnetic reluctance, and cause changes in the magnetic flux change of diode, magnetic sensor, magnetic flux changes will be caused once, change detection in the coil voltage. Determine the voltage detection coil changes in the relationship between stress and change, can be used to detect stress diode probe. According to the above principle, the magnetic force system should be the principle diagram shown in Figure 6.

4. A new method for measuring residual stress

4.1 Crack compliance method

Crack compliance method is a new type of residual stress testing technology, test results can well reflect the measured residual stress distribution on the cross section. In recent years, there are many people in the study of the crack compliance method testing theory and algorithm, and application flexibility. In foreign countries, Cheng [17] adopts elastic fracture mechanics theory on the calculation theory and test method to improve the crack compliance method in metal components, residual stresses of composite material detection has made great progress; Prime calculates the flexibility function corresponding to different interpolation function, make guidance for the selection of interpolation functions Prime; using the finite element method to calculate the crack compliance matrix, simplifies the calculation of stress intensity factor, and the test results of residual stress are Aluminum Alloy plate; Cheng and Prime of the crack shape on the influence of calculation errors, and pointed out that the elimination of shear stress influence and improve the method of strain measurement the sensitivity of the.

In China, there are many studies on the crack compliance method testing theory and engineering application, Zhang Danwen, Wang Qiucheng, Wang Shuhong [18] respectively by the crack compliance method distribution were detected on the residual stress of the rolled 7075 Aluminum Alloy plate, and the error of the crack compliance method uncertainty factors, the choice of interpolation polynomial and the study of convergence and stability.

Determination principle of crack compliance method is based on the principle of linear elastic fracture mechanics, the crack in the surface of measured object into a depth gradually increased to release the residual stress and residual strain, through the determination of parts of the surface of the release amount to determine the corresponding strain, displacement or angle of equivalent value to the analysis and calculation of residual stress. The results show that, compared with the incremental hole drilling method and X ray diffraction crack compliance method, with better sensitivity and accuracy, and can be used for determination of residual stress in components. As a new technology of residual stress test, the crack compliance method has great potential in engineering application, but the applicable range and the measurement error issues need further study.

4.2 Nano indentation method

The indentation test is a test technology to set up based on the Hertz theory, the contact indentation test nonconforming contact method belongs to the solid contact, the contact area between the object relative to the sample itself is very small, so the stress is highly concentrated in the contact region near 7. The complete indentation process consists of two loading and unloading processes. When the load is applied, the ind enter receives the external load and the sample surface. In the process of pressing head, the material undergoes elastic and plastic deformation. With the increase of the load, the depth of the ind enter is pressed into the surface of the material. In the unloading process, only the elastic displacement is restored, so the hardness and elastic properties can be obtained from the unloading curve. For perfectly elastic materials. The plastic deformation is zero, the loading curve and the unloading curve coincide, and the unloading curve of the perfectly plastic material is the elastic deformation which is perpendicular to the displacement axis.

With the rapid development of microelectronics and micro system research, the micro mechanical properties of materials will be developed, as nano indentation technique has the advantages of nondestructive test, mechanical properties of the material in the local small scope etc. Through the indentation test can be continuous determination of load displacement curve of the material, as shown in Figure 7, then evaluate its hardness, elastic modulus, plastic properties of nano indentation techniques commonly used theoretical methods of classical mechanics methods (Olive and Pharr [19]), the strain gradient plasticity theory, Hain-sworth [20] method, volume proportion method and molecular dynamics in addition, the finite element simulation method, also numerical indentation test commonly used in the film matrix combination system simulation. The indentation residual stress measurement method is the test method, the hardness reference strain measurement of blind hole method, according to the idea of the stress field and the formation of a new residual interference theory of stress measuring method. Characteristics of nano indentation technique in the high load and displacement resolution, can continuously record the change of load and displacement during loading and unloading (as shown in Figure 7), which makes the technology suitable for measuring mechanical properties of thin film materials, the technique also widely used in the study of mechanical properties in MEMS Thin film coating, and special functional materials and biological tissue etc.. At present, the method used in the world is more spherical head, the corresponding theory and test is more mature. China, 2008 chapter Shakespeare er Al interpretation measurement of residual stress in deposited nickel coating, with 2 kinds of theoretical models of 5 kinds of electrode-posited nickel coating without indentation depth was measured at X, and the measurement results and the ray method were compared and showed that the two results are similar.

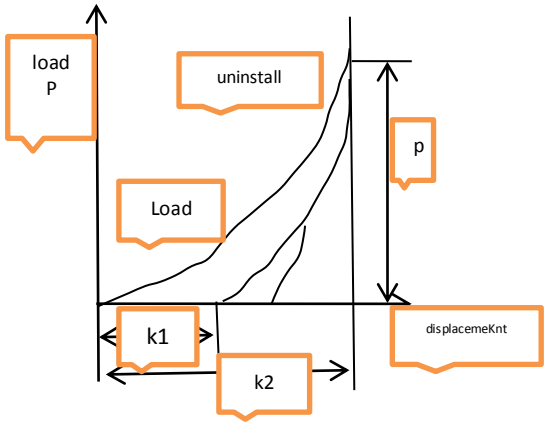

Figure 7. Typical load displacement curve

4.3 Laser ultrasonic measurement method

A lot of researches have been done to evaluate the near surface stress distribution by measuring the surface acoustic wave velocity with PZT transducer, EMAT probe and acoustic microscope. The results show that the distribution of the residual stress can be evaluated by measuring the variation of the surface acoustic wave velocity on the free surface of the measured material. However, the relative change of sound velocity caused by stress is very small, so it is difficult to detect. The laser ultrasonic nondestructive testing technology is developed in recent years, its significant advantage is the space and time of non-contact, high resolution, easy to achieve high precision measurement has been successfully used to characterize the surface properties of materials. The principle of laser ultrasonic method is using Nd: YAG (neodymium yttrium aluminum stone Liushi [20]) pulsed laser induced surface acoustic wave, and heterodox laser interfaith receiver. The residual stress distribution of the material can be reflected by the relative variation of the measured surface wave velocity at different positions. There is no residual stress. The stress distributions of 3 specimens with comprehensive residual stress and tensile residual stress were measured. The results show that the residual stress distribution can be relatively sound wave velocity changes in different positions, also confirmed that the laser generated surface acoustic waves and receiving technology is a non-destructive detecting the residual stress distribution should be effective method.

5. Summary and Prospect of various methods

In view of the different measuring principles of different methods, the resolution is different, the measurement range is affected by different interference and the stress distribution is different. Therefore, in the face of the measured results of various methods, broadly about comparability of measurement results is not scientific. It is better to measure the various kinds of materials and the residual stress of the structural parts made from these materials. These materials include ferrous metals, non-ferrous metals, glass, ceramics, magnetic materials, polymer materials, semiconductors, superconductors and nano functional materials, remnants of these materials and components after different heat treatment on the surface and internal stress measuring instrument can determine this, such as the determination of welding parts, casting parts, forging parts machining and the presence of residual stress, and after various heat treatment, surface treatment, shot peeing, vibration and residual stress corrosion induced by the stress measuring instrument in measuring the residual stress, the detected object does not cause any damage, and can measure the residual surface and internal structure stress. Because the magnitude and distribution of residual stress are different in different parts of the surface and interior, the stress changes include the difference of direction and size. The residual stress measurement instrument is the best mufti-purpose, can be used in the laboratory and carried to the field measurement of residual stress; can detect the sample and the actual detection of the residual stress of components can be measured; plane smooth specimen stress can be measured at the site of complex shapes (such as gear tooth or fillet etc.) of the residual stress; both manual measurement and automatic measurement. The whole set of instruments and equipment is also the best light weight, easy to carry, easy installation and commissioning, operation and maintenance features.

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