Development of state identification system for whole process of tensile fracture of steel bar based on magnetic field measurement

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Abstract—The large and small difficulties during the trial, a lot of places repeated the experiment many times, in order to avoid has omission cause the whole experimental process experiments to be carried out again. The experimental project has a large amount of data, so it is a test of the patience of team members in data processing. When the researchers process the data, you need to import the origin of many data, to draw out the change of the magnetic field intensity and the magnetic field gradient image, and the process we have a good command of origin usage skills, understand how vital it is to process data correctly at the same time, care and patience for scientific research employees are essential. This issue necessitates a greater understanding of mathematics, physics, and chemistry, which is made more difficult by the fact that the process of understanding the principle necessitates the use of these skills. The test results show that there is a good corresponding relationship between the magnetic induction intensity and the stress state of the steel bar. The normal residual magnetic induction intensity and the hysteresis loop area of the steel bar under the action of fatigue load show the three-stage change law of fatigue, which can be further applied to the steel bar. The state of stress is being tested.

1. Introduction
With the development of modern science and technology, especially the development of computer technology, the size of the instrument is getting smaller and smaller, the processing speed is getting faster, and the function is getting more and more powerful. The magnetic field detection technology continues to develop, and the magnetic field detection technology also continues to develop: magnetic force method, electromagnetic induction method, magnetic saturation method, electromagnetic effect method, magnetic resonance method, superconducting effect method, etc[1]. The continuous development of magnetic field detection methods has provided considerable convenience for later detection. Previously, the relationship between the stress state of the steel bar and the change of the magnetic field was studied based on the piezomagnetic effect. Through the axial tension static load test and the fatigue loading test, the characteristics of the piezomagnetic signal of the steel bar are analyzed. In short, after a year of careful study and practice, our ability to solve problems independently improved, the spirit of teamwork has been cultivated, the understanding of the reinforcement nondestructive testing has been further deepened, and the professional cognition is also more profound. This experiment inspired our enthusiasm for learning, cultivated our sense of innovation, and helped us to fight high in the future academic road.
2. Project completion status (whether the expected goal is achieved)

2.1. Developed the actual state recognition system for the whole process of steel bar tensile fracture based on magnetic field measurement

2.1.1. Development of state recognition system

There are four stages in the process of stretching a steel bar: elasticity, yielding, strengthening, and necking. When the steel bar is stretched to fracture, the fractured steel bar will still produce a self-balanced interior that remains in its object after the external force is eliminated. Stress, that is, residual stress. At this time, the residual stress still has a magnetic effect and generates a magnetic field, because the change of stress in the process will cause the change of the magnetic field strength after the steel bar breaks[3]. The purpose of this project is to identify the stress stage of the steel bar by measuring the magnetic field during the whole process from stretching to breaking of the steel bar.

Tensile fracture stress state of steel bar:

The development of a state recognition system for the whole process of steel bar tensile fracture based on magnetic field measurement includes two parts: the steel bar tensile fracture stage and the force state recognition system.

3. Data analysis method

3.1. Distance function analysis method

As a technical field, equipment and system fault diagnosis has made great progress since it was formally published in the early 1960s. The primary task of fault diagnosis is to find the cause of the fault, including the vertical cause between the system levels, the horizontal cause between the subsystems, the indirect cause, and the external cause. However, the previous diagnosis theories and methods generally focus on a single failure mode, and the consideration of the problem is relatively simple. With the large-scale equipment of generator sets and the complexity of the system, there is an urgent need to develop new diagnostic techniques and methods. Especially in the high-dimensional multi-mode problem, the use of clustering analysis and other methods has the disadvantages of huge calculation amount and difficulty in ensuring the convergence of the algorithm. The distance classifier is particularly superior. The feature vector composed of n feature parameters is equivalent to a point on the n-dimensional feature space. Research has proved that the pattern points of the same state are clustered. The mode points of different types of states have their own clustering domains and clustering centers. If the known clustering domains of the mode points of various states can be used as the reference mode in advance, the distance between the mode to be checked and the reference mode can be used as Discriminant function to determine the attributes of the state to be checked.

3.2. Euclidean distance

In Euclidean space, set the vector \( x = (x_1, x_2, ..., x_n) \) \( T \), \( z = (z_1, z_2, ..., z_n) \) \( T \), the closer the distance between the two points, the greater the similarity. It can be considered as belonging to the same clustering domain, or belonging to the same category, this distance is called a point. Research has proved that the pattern points of the same state are clustered. The mode points of different types of states have their own clustering domains and clustering centers. If the known clustering domains of the mode points of various states can be used as the reference mode in advance, the distance between the mode to be checked and the reference mode can be used as Discriminant function to determine the attributes of the state to be checked.

4. Experimental procedure

Experimental assumptions before the test:
Specimen and instruments required for the test: use a smooth steel bar with a circular cross-section, a single diameter of 14mm, a length of 800mm, a three-dimensional scanning device based on metal magnetic memory technology, and a universal testing machine[4].

The three-dimensional scanning detection device is an automated scanning platform assembled by 3 mechanical axes and high-sensitivity magnetic sensors. Installed on a movable base plate, it can measure the magnetic field around the universal testing machine. The magnetic sensor adopts a three-axis intelligent digital magnetometer (range: $\pm 2 \times 10^{-7}$T, resolution: $6.7 \times 10^{-9}$T), which outputs magnetic signals and processes them, and outputs the magnetic induction intensity in 3 directions, such as x, y and z. Component, three independent bridges can be used to detect the magnetic induction intensity components $B_x$, $B_y$, $B_z$ of the x, y, and z axes of the magnetic field, which can be used to identify the force state of the steel bar[2] [6].

Working principle: The universal testing machine is used to adjust the tension of the steel bar specimens in different stages. A three-dimensional scanning monitoring instrument is set to scan the magnetic signal next to the specimen in real time, and the magnetic field magnetic induction intensity $B_x$, $B_y$, and $B_z$ directions of the specimen are calculated. $B_y$, $B_z$, record the experimental data, and generate the corresponding magnetic induction intensity curve[5].

5. Data processing stage

(1) Processing test data fitting curve

(2) Forming magnetic field characteristic parameters: maximum value, minimum value, change trend

(3) Using the distance function classification method, use the distance between the magnetic field characteristic parameters of the test piece and the reference magnetic field as the judgment function: take the highest point as the reference

(4) Judge the stress state of the steel bar specimen

Elastic stage: As the tension increases, the steel bars begin to stretch. Because stress and strain are a straight line, that is, the relationship between the two is proportional. We call it the elastic phase;

Yield stage: Under the condition of constant external force, the deformation of the material will continue to increase, the deformation will increase sharply, and it is in a stalemate stage;

Strengthening stage: After the yielding stage, the test piece recovers its bearing capacity, and the load needs to be increased to increase the deformation of the test piece. This stage is called the strengthening stage.

Necking stage: After the load reaches the maximum value, the cross-sectional area of a certain part of the specimen is obviously reduced, and the phenomenon of "necking" appears.

No. 3 steel bar

![Diagram of the relationship between stress and strain](image-url)
Figure 1 shows that the yield point of No.3 steel bar appears at a stress of about 621.5546Mpa. Because the instrument cannot measure the stress-strain relationship between the strengthening and necking stages, there are only curves for the elastic and yielding stages, not the strengthening and necking stages.

5.1. The relationship between stress and total magnetic induction

![Fig.2 The relationship between stress and total magnetic induction](image)

The maximum value of the curve is selected as the characteristic parameter of the magnetic field, and other points are analyzed. The curve shows a trend of increasing first and then decreasing. The yield point is marked as the yield point in the figure. The distance function analysis method shows that the distance between the highest point and the yield point in Figure 2 is 3668.293, and the distance between the highest point and the starting point is 15844.436. There will be two different stresses at the left and right of the same magnetic induction intensity. The state where the stress is greater than the highest point is not the same as the state where the stress is less than the highest point. The distance between the points in the figure is less than 3688.293 is the elastic stage, and greater than this is the yield stage.

![Fig.3 The relationship between stress and x-axis magnetic induction](image)

The yield point is marked as the yield point in the figure. The distance function analysis method shows that the distance between the highest point and the yield point in Figure 3 is 5933.658, and the distance between the highest point and the starting point is 1297.093. There will be two different stresses at the left and right of the same magnetic induction intensity. The state where the stress is greater than the highest point is different from the state where the stress is less than the highest point. If the distance between the points in the figure is less than 5933.658, it is the elastic stage, and greater than this value is the yield stage.
The figure is marked as the yield point. Using the distance function analysis method, it can be obtained that the distance between the highest point and the yield point in Figure 3 is 778.089, and the distance between the highest point and the starting point is 280.386. There will be two different stresses at the left and right of the same magnetic induction intensity. The state where the stress is greater than the highest point is different from the state where the stress is less than the highest point. If the distance between the points in the figure is less than 778.089, it is the elastic stage, and greater than this is the yield stage.

The figure is marked as the yield point. The distance function analysis method can be used to obtain that the distance between the highest point and the yield point in Figure 3 is 6497.185, and the distance between the highest point and the starting point is 1908.821. There will be two different stresses at the left and right of the same magnetic induction intensity. The state where the stress is greater than the highest point is different from the state where the stress is less than the highest point. The distance between the points in the figure is less than 6497.185 is the elastic stage, and the value greater than this is the yield stage.
5.2. The relationship between stress and magnetic field gradient

It can be seen from Figure 6 to Figure 9 that (1) the fitting curve of the magnetic field gradient in the x-direction and the magnetic field gradient in the y-direction of No. 3 steel bar is rather chaotic. Calculation and analysis (2) The yield point appears when the stress is about 621.5546Mpa. (3) The relationship between the stress and the magnetic field gradient shows a trend of first increasing and then decreasing in the z-direction and the total magnetic field gradient direction. The yield point is at the stress Appears at about 621.5546Mpa, that is, when the stress is greater than 621.5546Mpa, it is the yield stage.

No. 4 steel bar
The analysis shows that the yield point of No. 4 steel bar is that the stress value reaches about 619.1741 Mpa.

The figure is marked as the yield point. Using the distance function analysis method, it can be obtained that the distance between the highest point and the yield point in Figure 2 is 7568.123, and the distance between the highest point and the starting point is 597.702. There will be two different stresses at the left and right of the same magnetic induction intensity. The state where the stress is greater than the highest point is different from the state where the stress is less than the highest point. If the distance between the points in the figure is less than 7568.123, it is the elastic stage, and greater than this value is the yield stage.
The figure is marked as the yield point. The distance function analysis method can be used to obtain that the distance between the lowest point and the yield point in Figure 2 is 1750.324, and the distance between the lowest point and the starting point is 1038.186. There will be two different stresses on the left and right of the same magnetic induction intensity. The state where the stress is greater than the lowest point is not the same as the state where the stress is less than the lowest point. The distance between the points in the figure is less than 1750.324 is the elastic stage, and the state greater than this is the yield stage.

Fig.13 The relationship between stress and z-axis magnetic induction

The figure is marked as the yield point. The distance function analysis method can be used to obtain that the distance between the highest point and the yield point in Figure 2 is 6965.266, and the distance between the highest point and the starting point is 1570.455. There will be two different stresses at the left and right of the same magnetic induction intensity. The state where the stress is greater than the highest point is different from the state where the stress is less than the highest point. If the distance between the points in the figure is less than 6965.266, it is the elastic stage, and greater than this value is the yield stage.

Fig.14 The relationship between stress and total magnetic induction

The figure is marked as the yield point. Using the distance function analysis method, it can be obtained that the distance between the highest point and the yield point in Figure 2 is 7152.906, and the distance between the highest point and the starting point is 1108.258. There will be two different stresses at the left and right of the same magnetic induction intensity. The state where the stress is greater than the highest point is different from the state where the stress is less than the highest point. If the distance between the points in the figure is less than 7152.906, it is the elastic stage, and greater than this value is the yield stage.
Fig. 15 Relationship between stress and magnetic field gradient in the X-axis direction

Fig. 16 The relationship diagram of the magnetic field gradient in the y-axis direction of the stress

Fig. 17 Relationship between stress and magnetic field gradient in the z-axis direction

Fig. 18 Relationship between stress and total magnetic field gradient

From Fig. 15 to Fig. 18, it can be seen that (1) the fitting curve of the magnetic field gradient in the x direction and the magnetic field gradient in the y direction of No. 4 steel bar is confusing, and the distance function analysis method cannot be used for calculation and analysis. (2) The stress at the yield point is 619.1741. (3) The relationship between stress and magnetic field gradient appears in the z-direction and the total magnetic field gradient. The fitting curve first increases and then decreases. The yield point appears to the right of the stress of 619.1741 Mpa, that is, the stress is greater than 619.1741 Mpa. Yield stage.

6. Conclusion
For the motion control system, in order to reduce the influence of some necessary electrical appliances on the experimental magnetic field gradient, the extension rod made is longer, and its inherent instability will make it jitter during the motion and cause the collected data to fluctuate. In the experiment of this project, we strengthened the experimental instrument and controlled the movement speed of the three-axis magnetic field probe with the guide rail so that the jitter caused less error on the experimental results. For the stretching system, the magnetic field of the jack and some small parts will have a great impact on the experimental results. In the test of this project, the magnetic field interference of the jack is by extending the stretching device and eliminating the magnetic field through distance. For the small parts used in the experimental device, we use parts made of aluminum and stainless steel, which have minimal interference to the magnetic field of the test piece. Through the analysis of the experimental data, the environment has a certain interference to the experimental data. The knowledge of chemistry and physics related to the magnetic field is limited. During the experiment, many problems will be encountered, which can be solved by repeatedly checking the literature and mastering the knowledge points.
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