STUDY OF STRESS-MAGNETISM COUPLING FEATURE ON BOLTED CONNECTIONS UNDER STATIC TENSILE CONDITION

TU QINGSONG, ZHANG WEIMIN
School of mechanical engineering, beijing institute of technology, beijing, 100081, china.

ABSTRACT
The three-dimensional weak magnetic signals of bolted connections under static tensile condition were studied, and a possibility of evaluating the feasibility of bolted connections under geomagnetic field condition was discussed. A new magnetic memory detector was used to obtain the 3D weak magnetic signals on the surface of specimens. The finite element method was introduced to analyze the bearing threads. The result shows that there is a strong relationship between magnetic signals and stress, and the magnetic signals got from two different structures of bolted connections show little difference on charactering the area of stress concentration, which means it is feasible to use this method to detect stress and fatigue of work piece in practical engineering environments.
KEY WORDS
Weak Magnetic Signal; Bolted Connection; Static tension; Finite element

1 INTRODUCTION

Bolted connection is one of most common used ways of mechanical connections. However, its complicated and unsymmetrical stress distribution always lead to plastic deformation, which results in a decrease of fatigue life [1]. Consequently the detection and evaluation for the stress and deformation of bolted connection is of considerable importance to secure machineries[2]. To the present, conventional nondestructive testing methods are inadequate to execute effective screw detection. It is exhilarating that the metal magnetic memory (MMM) testing provides an unusual, unparalleled and as well valid approach to investigate the stress condition and deformation where stress concentrates, on account of its excellent sensitivity to the stress concentration. For the sake of exploring the relationship between the weak magnetic signals and stress, *S45C* is selected in this disquisition to manufacture three different screw joints with specific heat treatments.

2 APPARATUS AND FACILITIES

The WDW-E1000, an omnipotent tensile testing apparatus controlled by computer, with 10 ton rated load, was adopted in the experiment requiring 7 ton load calculated approximately.

The MMM-System TSC-3M-12, was utilized to observe weak magnetic memory signals H_x in the axial directions and H_z in the radial direction, and H_y in the tangential direction [3]. As shown in Fig.1, two internal coils are located vertically to sense signals in two particular directions. Both coils are equipped with a signal acquiring circuit, a processing circuit, a mutual screen to depict the real-time signal curves and a shared memorizer to storage data.

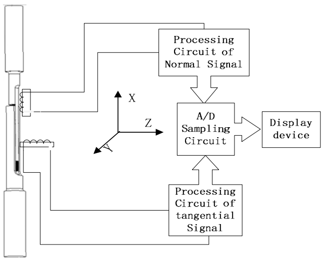


Fig.1 The principle of tester

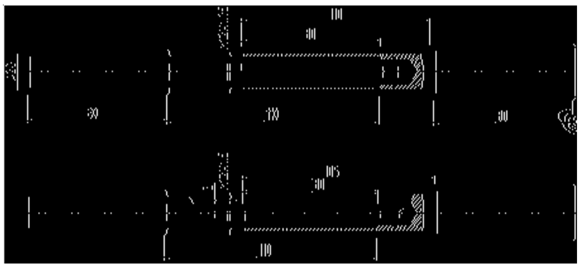


Fig.2 Specimens

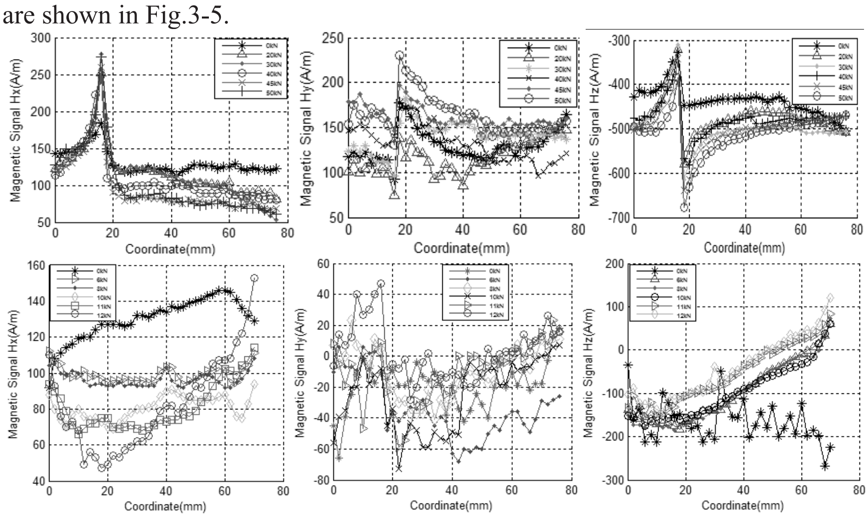
3 EXPERIMENT AND RESULTS

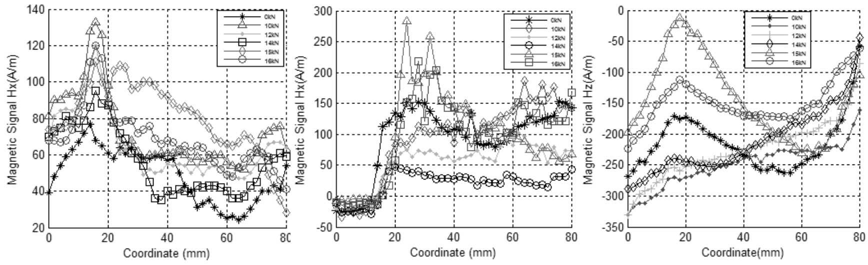
Three specimens made of *S45C*, assigned from 1 to 3, were involved in this experiment, as shown in details with crucial structure dimensions in Fig.2, to explore variation characteristics of weak magnetic signals under diverse initial circumstances and different loading conditions. The load step decreased gradually with the ballooning load and touched the minimum when the specimen fetched its yielding point, indicated in Table 1.

Table 1 Different loads applied on different specimens (All loads in kN)

	First Load	Second Load	Third Load	Forth Load	Fifth Load
No.1	20	30	40	45	50
No.2	6	8	10	11	12
No.3	10	12	14	15	16

A measurement and storage execution concerning magnetic signals on the surface of joints in the vertical, tangential and axial directions followed every load intermission. Detection points located at the root of screw thread with 1.7mm spacing. Superficial three-dimension signals detected in this experiment are shown in Fig.3-5.





Axial(X) Magnetic Signal tangential (Y) Magnetic Signal Normal(Z) Magnetic Signal

Fig.3-5 The distribution of three-dimension signals of specimen1-3

From figures above, with the accretion of load, the characteristic value point of magnetic memory signals for every specimen gradually moves towards the ninth measurement point which is placed around the first engaged thread. Signal characteristics vary from particular specimens and specific directions. Fig.3 shows that H_x achieve the max value at this point while H_y and H_Z mutate obviously; Fig.4 shows the same phenomenon as fig. 4 in H_x and H_y, while has a smooth curve in H_Z; Fig.5 shows that H_x, H_y, H_Z achieve the max value at this point.

4 ANATOMY OF EXPERIMENTAL PHENOMENA

As the result shows, a precipitous oscillation of magnetic signals arises in the first engaged thread for all specimens. From this conspicuous phenomenon and the widely acknowledged theory of magnetic memory testing, conclusion can be drawn that the stress converges in the first matched thread.

In Fig.3, signals of specimen 1 increased as the load increased, while signals of specimen 2 decreased as the load increased and signals of specimen 3 increased firstly and decreased then as the force increased. According to approach theory, the change of magnetic signals depends greatly on the initial conditions. If the value of initial magnetic flux density is above the hysteresis loop, the magnetic signals will increase as the load increase; however, signals will decrease when initial flux density is under the hysteresis loop [4]. Result of specimen 3 shows the different changes of magnetic signals between elastic state and plastic state, which indicate that signals will increase as load increase in elastic state and decrease as load increase in plastic state [5,6].

For specimens 2 and 3 without any heat treatment, magnetic memory signals appear irregular and cannot demonstrate the stress distribution or magnitude in accordance with the load applied at the beginning of loading. Actually this phenomenon emerges as a consequence of the residual stress of the mechanical processing which dominates the overall stress distribution. With the increasing of load, the magneto-elastic energy inside the specimen soars, gradually disturbing the magneto equilibrium and giving rise to a rearrangement of magnetic domains. Accompanied by this transformation, magnetic signals detected on the surface, start to reflect the artificial stress distribution.

5. COMPARATIVE ANALYSIS ON THE STRESS AND MAGNETIC SIGNALS

Finite element analysis of screw joints is a not only complex but also challenging nonlinear conundrum, entangled with geometrically nonlinear analysis, material nonlinear investigations and nonlinear contact. The stress distributions of specimens 1, 2 and 3 under the respectively ultimate loads is caculated Take specimen 2 for example, the yielding limit $\sigma_s = 335MPa$ and elastic modulus $E = 201e9MPa$, bilinear isotropic hardening was used to simulate the nonlinear progress, whose result was shown in Fig.6.

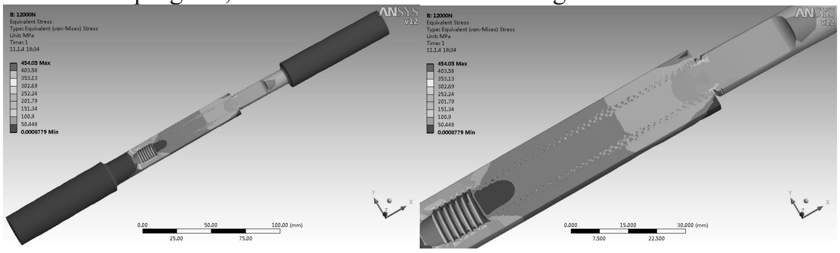
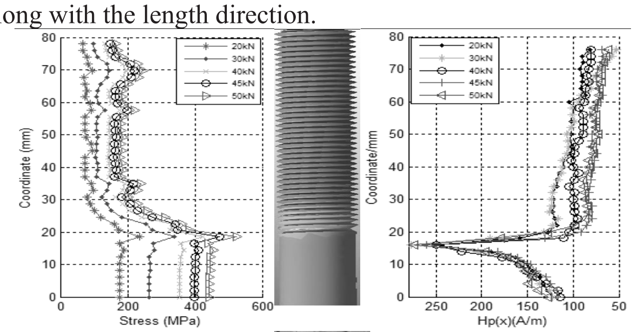
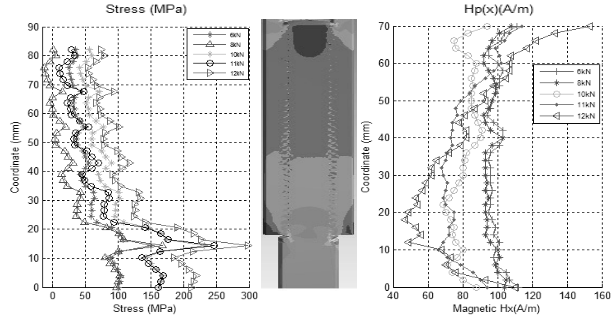


Fig.6 Stress distribution of specimen 2 under 12kN

The analysis indicates that the stress reaches its zenith in the first engaged thread and surpasses the yield strength for all specimens, which is highly identical with the experimental results [7].

Based on a comprehensive consideration of concrete damage locations, magnetic signals detected and the finite element analysis, the sensitivity of the magnetic memory method to the stress concentration can be distinctly revealed. Comparison between the normal magnetic signals and the stress calculated by the finite element analysis of specimens 1-3 is shown in Fig.7-9 correspondingly. The left figure shows the stress calculated from finite element method changes along with the length direction and the right figure shows the magnetic signal H_x changes along with the length direction.





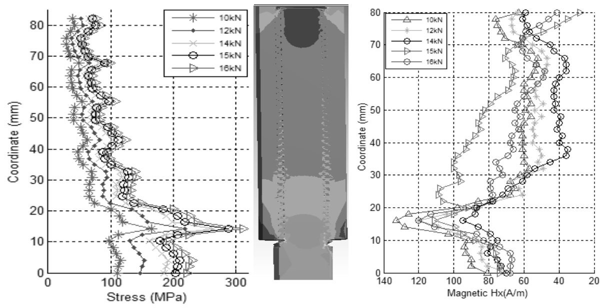


Fig.7-9 Comparison between the normal magnetic signals and the stress of specimen 1-3

It can be manifestly perceived that the first engaged thread of a particular screwed connection sustains the severe stress concentration. The result shows that the stress-magnetism feature of both half cut-off and normal bolted connections is obvious, which means that it is feasible to use weak magnetic signals on the surface of bolt specimens to evaluate failure life.

6. CONCLUSIONS

Based on the experiment of detecting 3D weak magnetic signals on bolted connections under static tensile conditions and finite element analysis, conclusions can be drawn firstly that the 3D weak magnetic signals change obviously as loads increased. Meanwhile, stress concentration and plastic deformation occurred on some special area. Thirdly, the weak magnetic signals have certain correlation with many factors, such as: ultrafine organization state of specimens, initial residual stress, thread tooth type and specimen shape. By compare signals of normal threads and half cut-off threads, there is little influence of the existence of threaded sets, which indicates that the method of using metal magnetic memory to detect the bolted connections is feasible.

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