FULL-FIELD STRESS ANALYSIS FOR PREVENTION OF FAILURE OF AGRICULTURAL MACHINERY

Paper No.66. Wei Songling, Professor
Chinese Academy of Agricultural Mechanization
Sciences, Beijing, China

ABSTRACT

When the important structures or components of agricultural mechinery are designed, the full-field methods of stress analysis can provide enough information in order to obtain lighter weight and prevent failure.The photoelasticity has been applicated to solve many practical engineering problems. The coating method provides full-field information, enabling the engineers to determine the complete distribution of surface strains and directly highlighting severely strained areas, especially for the welded frames of agricultural machinery. A combined method of model and prototype for strain analysis of excavator has been successfully applied to improve design. A measuring and recording system controlled by micro-computer and application software for dynamic event was studied. It can be widely used in structural failure analysis under cyclical loading. Typical applications concerned stress field of crack tip and failure analysis of some mechanical structures are introduced briefly in this paper.

Key words: Full-field analysis, stress, failure

INTRODUCTION

The agricultural machinery are operated in bad working conditions and subjected to complex loadings. The seasonable operations are required owning to plants growing needs. The structural failure should be avoided in busy farming season, hence reliable structural designing based on stress analysis is very important.

When the complex mechanical structures are analyzed, many experimental methods can be used to determine the distribution of stresses and strains, such as strain gages. Unfortunately, strain gages data only at the points where they have been mounted and little information is learned about other regions on the surface of the studied objects, and it is limited to analyze plastic state. As the locations of strain gages are depended on the experience of engineers, sometimes the sources of fatigure causing failure would be neglected.

Photoelasticity is one of experimental methods for analyzing stress or strain fields in mechanics. It deals with the effects of stress and or strain up on light. The traditional two and three dimentional photoelasticity can provides full-field data to determine stresses at points on the surface or in the interior of the speciman, precise results can be obtained. As classical photoelasticity requires the use of models fabricated from transparent birefringent polymers, and this limits the applicability, but these methods still can be used for solving some practical engineering problems of agricultural machinery. It is necessary to establish the similar relation characterized agricultural machinery and to apply the analogue loadings to model. Another method called the photoelastic coatings. The coating is a thin layer of birefringent material- usually a polymer that is bonded integrally to the flat or curved surfaces of the prototype being analyzed for stress. When the prototype is loaded, the surface strains are transmitted to the coating, reproducing the prototype strain field in the coating. To establish a time saving method under static loading and a system of structural analysis under dynamic loading is very important.

BASIC PRINCIPAL

All methods of photoelasticity are based on the stress- optic law. The relation between stresses and the indices of refraction for temporary birefringent materials in the plane stress condition were formulated by stress- optic law as follows:

$$\sigma_1 - \sigma_2 = \frac{Nf_\sigma}{h}$$

With birefringent coatings, the light traverses the model twice, so the form of stress optic law is modified as

$$\sigma_1^c - \sigma_2^c = \frac{Nf_\sigma}{2hc}$$

where $\sigma_1 - \sigma_2$ = difference of principal stress

$N = R / 2\pi = \delta / \lambda$ = relative retardation in terms of complete cycles of the radiation used;

δ = relative retardation, λ = wave/ length of light;

N is also called the " fringe order" and is wavelength dependent.

$f_\sigma = \lambda / C$ = material fringe value, C = relative stress- optic coefficient; it represents the principal stress difference necessary to produce unit change in the fringe order in a model of unit thickness

h = thickness of birefringent materials

C is used as a superscript and a subscript to refer to application of the stress-optic law to photoelastic coatings.

In the three dimensional condition, three equations can be established to solve three stress components on surface. The oblique- incidence method is frequently used to supply the relationship between stresses and measured fringe orders.

APPLICATIONS IN AGRICULTURAL MACHINERY BY TWO AND THREE DIMENSIONAL PHOTOELASTICITY

Two dimensional photoelasticity:

In conventional two dimensional photoelasticity, a geometrically correct scaled model is machined from a flat, optically isotropic plate of a suitable transparent material. The model is placed in a polariscope with its plane normal to the axis of the polariscope; it is loaded in directions in the plane of the model plane.

Although this method has been applicated for many years, it is still used to solve some mechanical problems even which of them seems to be complex. For example, the cutter bar of havaster matched with tractor appeared fracture in working condition, it was caused by stress concentration of hole of fixed bolts. The optimizing method was adoptted by means of model modification. As Fig.1. Among models a- d, Fig.1 d is a successful design. The very interesting result was that the fracture of cutter bar was solved by removing metal, not increasing metal. The reason is that the stress distribution was symmetrized. Another example was to obtain the coefficient and location of stress concentration of hook for rapid connection between tractors and agricultural implements. The isochromatic patterns of hook are shown as Fig.2. The stress concentration was discovered on the point where is lower than the level of the hook center with an certain angle, differing from theoretical solution.

Three dimentional photoelasticity:

Three dimentional photoelasticity by the stress - freezing method still is a powerful method of experimental stress analysis. A model made from optically sensitive polymers is heated to a stress - freezing temperature. It is then loaded , slowly cooled to room temperature, and the loads removed Model keeps the stress state similar to prototype. After stress freezing, the three dimensional model is usually sliced to remove planes of interest, these can than be examined individually to determine the state of stress existing in that particular plane or slice. The results from model analysis is converted to results of prototype by the laws of similarity, thus the model design should meet similarity rules. A typical application in agricultural machinery is plough leg. The stress concentration was discovered at the hole of fixed bolt from isocromatic pattern as Fig.3. Another example is the design of universal joint. The aim of design is to get a lighter weight and a highter strength. The stress distribution in various sections especially curved part is obtained as Fig.4. The maximum stress point is located on the inside of curved part in dangerous section. The analysed results is used for improving design.

TYPICAL APPLICATIONS BY PHOTOELASTIC COATING

The photoelastic coating method has many advantages compared to other methods of experimental stress analysis. It provides full-field information, enabling the engineers to determine the complete distribution of surface strains and directly highlighting severely strained areas. It can be used directly to prototype. This method is also very useful in the analysis of complex nonlinear stress situations, of course, strain of measured point needs to identify, stress value is also converted from elasticity to plasticity. However, both static and dynamic strains can be measured by coating.

The frames welded with steel are widely used in farm machinery, construction machinery, automobile and aerospace engineering. While these frames are subjected to complex loadings, stress concentrations are occurred on joints where shapes were changed steeply. In order to improve structural reliability and make lighter weight, the most important step is to obtain full-field stress distribution. The stress concentration coefficient is an important criterion for designing machinery. It can be obtained by coating method including the influence of welded seam shape. Considering the difficulties to bond a large amount of coatings on the surface of large structure directly and to measure fringes under working condition, hence, a combined method of model and prototype is selected. Firstly, the surfaces of excavator model are bonded with coatings made by birefringent material, and subjected to loads analogous to actrual loads. The peak stress occurred in the fillet of the connecting plate. Secondly, some high stress areas where was discovered from model testing are bonded with coatings for checking again. After redesign, the allowable limit load applied to prototype is increased by 40 percent.

FULL-FIELD ANALYSIS UNDER DYNAMIC LOADING

The loading studied in paper is cyclic loading. It is one of the main loading forms acted on the machinery which are driven by power (motor, engine or other hydraulic transmission). These machinery are driven to make rotating motion or reciprocating motion. Analysis of dynamic events under cyclic loading requires that fringe pattern is enable to observe and record. At present, many techniques have been adoptted, such as high speed camera, sparkle camera, TV camera, but they are very expensive, and reflection polariscopes needs to be reconstructed. The reflection polariscope equipped with a strobscopic light is well suited for dynamic stress analysis under repetitive loading. To keep the stroboscopic light synchronized with the motion of studied event to follow the changes that occur in the stress field with time is absolutely necessary. For solving industrial problems, phase identification and shift, as well as automatic recording of fringe patterns were studied. A dynamic analysis system has been developed by author, it consists of hardware and application software as Fig.5.

Hardware

Dynamic analysis system consists of reflection polarscopes, microcomputer, strain amplifier, A/D converter, input/output interface and computer-camera interface.

The signals are picked up from the surface of structure under dynamic loading and inputted into Micro-Computer via strain amplifier A/D converter and processed by software. The stroboscope and camera are controlled by output signals via interface.

Software

System software is preprogrammed to perform all functions. It can identifies phase and shifts phase, searches for transient phase at maximum stress state automatically. It can ensure the flashes of stroboscope to synchronized with the motion of studied event. A common camera is controlled to record the fringe patterns at regular intervals via the computer-camera interface.

The stress field of crack tip was studied by the dynamic system. When crack carrier was loaded, the fringe patteern appears in a butterfly shape. After measuring the order of fringes, the stress intensity factors can be calculated. It is an important criteria to evaluate crack propagating. The fringe patterns of crack tip at various phased under dynamic loading are recorded sequentially by dynamic analysis system. The serial photographs were taken by general camera automatically. In order to get the amplified fringe patterns, a XR RIKENON P zoom 70- 210 / 4 - 5.6 camera with a len for short distance focusing was adoptted.

CONCLUSIONS

(1) The full-field stress analysis is an important method for prevention failure of agricultural machinery.

(2) Photoelasticity is still one of effective methods for improving reliability of components and structures. Many applications in agricultural machinery have been researched successfully.

(3) The coating methods very useful for full-field structural analysis. An combined method of model testing and prototype testing was developed.

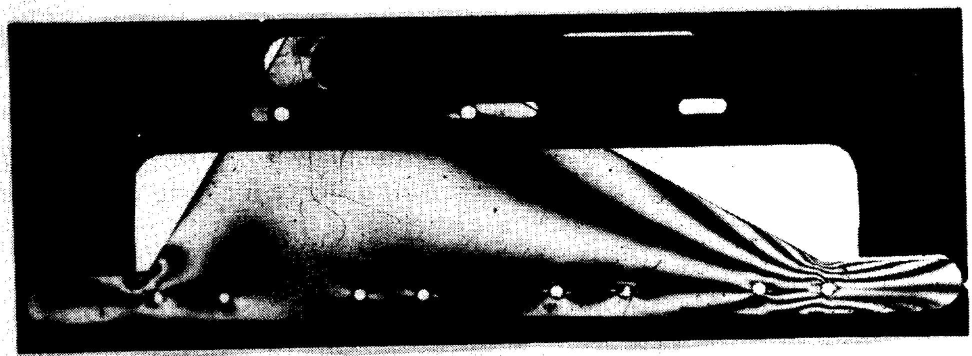
(4) Full-field analysis under dynamic loading can be performed by system established in this paper. It can be widely used in structural failure analysis under cyclical loading. The system has multi-functions intelligently and automatically. Serial photographs of crack tip under dynamic loading were taken by programme-controlled general camera.

REFERENCES

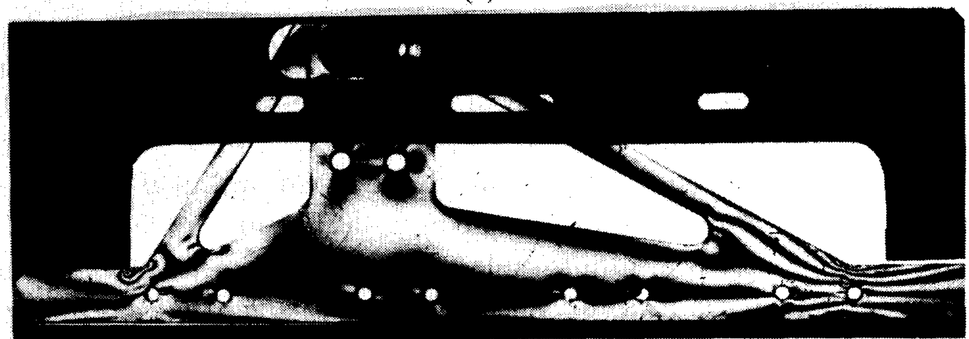
1. Zandman. F. et al. 1977. Photoelastic coating. SESA Monograph 3. Iowa State University Press. AMES IA: 31-46

2. Wei Songling. et al. 1985. Photoelastic coating method applied to large thin-walled structures. Proceedings of the International Conference on Experimental Mechanics. Beijing, China: 193-198.

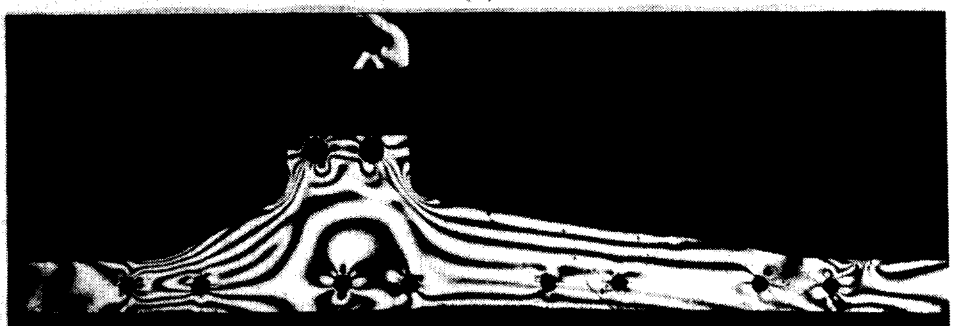
3. Wei Songling. 1995. Full-field method of failure analysis for mechanical structures. Proceedings of International Conference on Failure Analysis and Prevention. Beijing, China: 341-345.



(a)



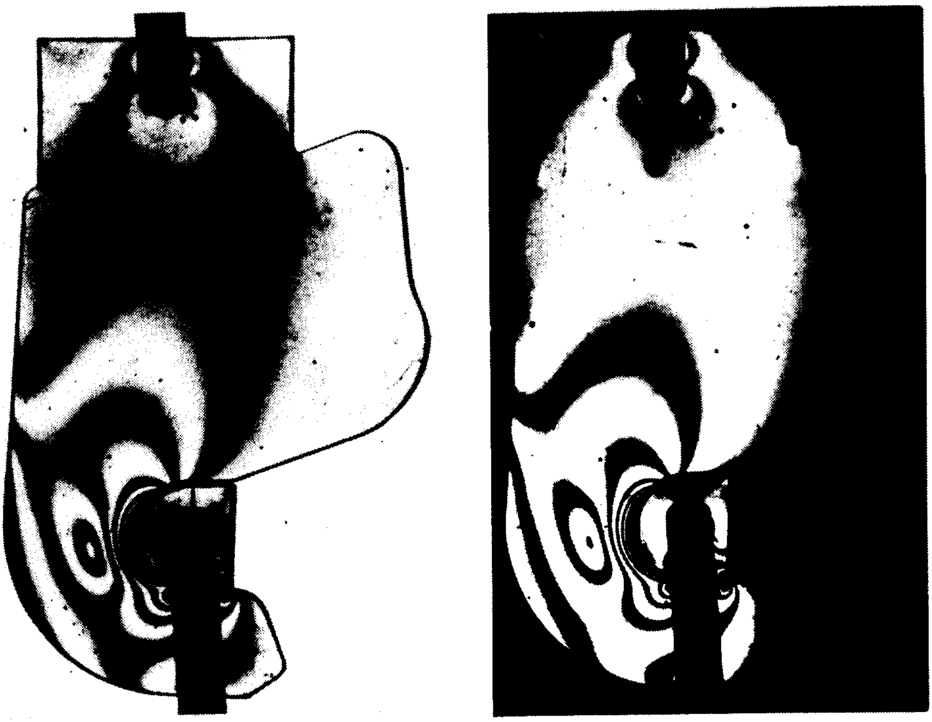
(b)



(c)

(d)

Fig.1 Stress distribution of havaster cutter bar
(a) original (b)(c) modified (d) final



(a) (b)

Fig.2 Isochromatic patterns of hook for rapid connection
(a) light field (b) dark field

(a)
(b)

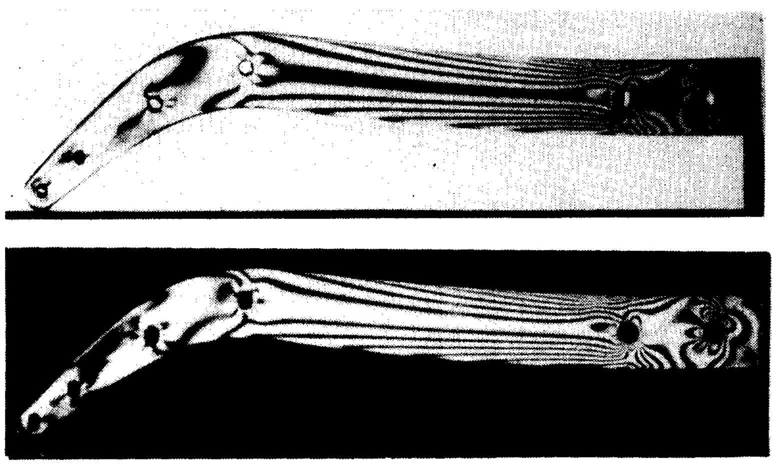


Fig.3 Stress concentration of plough leg
(a) light field (b)dark field

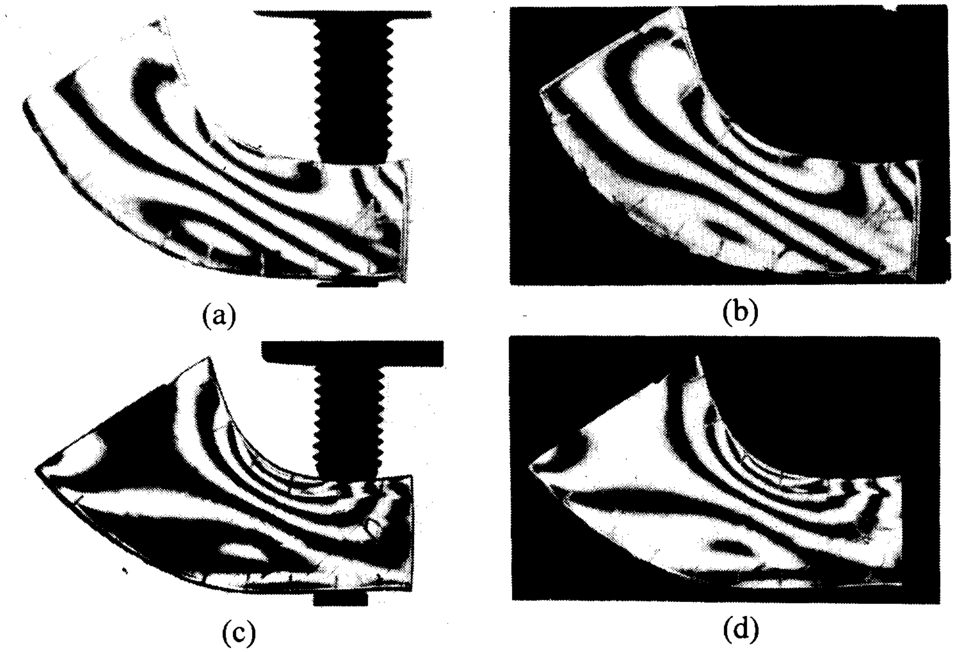


Fig.4 Isochromatic patterns of stress freezing slices of universal joint model
(a)(c) light field (b)(d) dark field

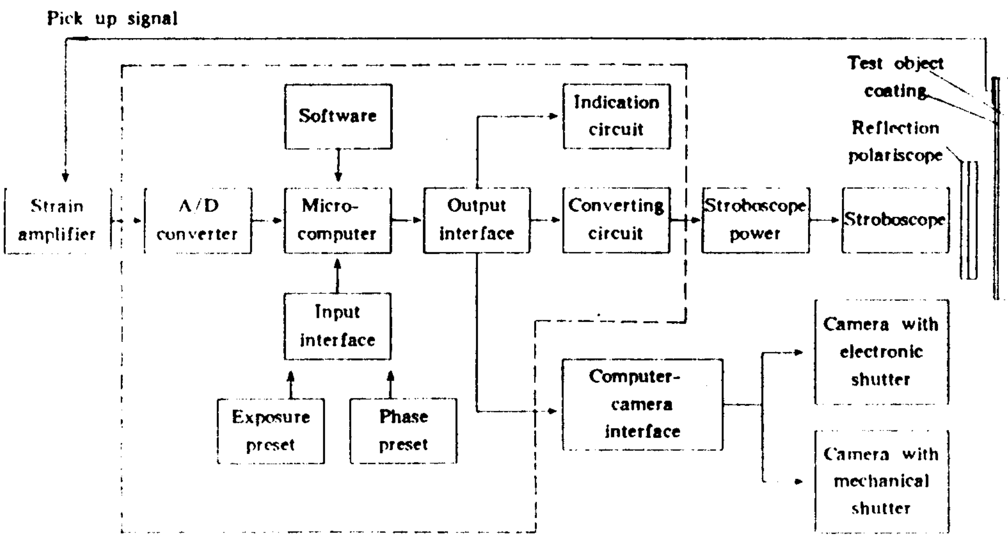


Fig.5 Block diagram of the dynamic analysis system