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SUMMARY

This article introduces the status and results of the use of a type of large-scale internal optical path vacuum stressing laser holographic nondestructive testing instrument in checking for viscosity flaws along layer surfaces of fuel packs in the motors of solid fuel rockets. Moreover, it discusses the advantages and disadvantages of carrying out this type of check using methods incorporating thermal stressing and vacuum (low pressure) stressing.

(1) Introduction

Holographic photography is a branch of research which makes use of the principles of interference and refraction to record and reproduce the light waves from objects. (1) Making use of these principles, we are able to take the light rays from an object being photographed and, with corresponding phase and amplitude, store these signals in a recording medium (a holograph). After this, it is possible to easily reproduce it.

On the same holograph, it is possible to record two (or more than two) light wave signals. Take for example, the light wave information making a linear recording of a certain stationary object (first exposure).

$$O_{1(x,y)} = O_{01(x,y)} e^{i\varphi_{1(x,y)}} \qquad (1)$$

After this, then the object is turned adding a certain stress (this is called the stressing process.) Under the influence of this stress, the object in its original position makes a minute change in its form and position. The light wave information which we get at this time

$$O_{2(x,y)} = O_{02(x,y)} e^{i\varphi_{2(x,y)}} \qquad (2)$$

is recorded linearly on the same recording medium (the second exposure.) Holographic images which are obtained in this way, if they are used to compare with totally identical reproduced optical illuminations made at the time of the recording, then, the light waves from the surface of the object both before and after the movement will be simultaneously produced, and interference will occur. The distribution of optical strength in the reproduced images

$$I \propto 2O_s^2[1 + \cos(\varphi_2 - \varphi_1)] \qquad (3)$$

varies as a cosine function. The cause of the cosine nature of the variance is that it is a function of the phase difference of the light coming from the object caused by the movement and shape change of the object. This is nothing except an interference image from the twin holograph exposures. Holograph interference, except for the two exposures described above, also interfere in many ways such as the real time interference method, the time average method, and the double wavelength method. However, it goes without saying that the working principles of the interference methods are all comparisons of a two or more wavelength form.

The interference patterns formed by the interference images of the holographs reflect outlines of equal movement along the direction of observation; moreover, the distance between each interference line, which represents the amount of movement represented on a rectalinear surface,is approximately equal to half the wavelength of the light used in the interference. It is precisely because of this that we are speaking of the use of holographic interference methods in the realm of nondestructive measurements technology. It is only necesary for the object being checked, under the application of stressing forces, to have the nominal sections of its surface produce even or regular minute transformations, and sections of the object's surface which contain interior flaws, because of the physical and mechanical nature of their changes,produce differing, localized transformations. The numerical values of these localized changes, when they are small enough to be in a range corresponding to the original wavelengths of the light used in the interference, will then cause in the holographic interference d-distribution patterns, in the vicinity of flaws, clear deformities, which allows the flaws to be discovered. Obviously, laser holographic interference measurement technology can be applied to nondestructive measurements and checks, and these applications will possess relatively high test sensitivities as well as positional accuracy. This possibility is clearly worth looking at. Nondestructive checks have advantages in such areas as contamination, and, because of this, it has become a lively new possibility among inspection methods, which has caused universal interest inside and outside China. In the area of nondestructive inspections of the quality of viscous connections along layer boundary surfaces in the propellant packs of solid fuel rocket motors, it has also given rise to a large amount of research work. (2)(3)(4) below will introduce us to many of the results of this work which have been obtained recently

(2) Selection of Stressing Methods

The selection of the most appropriate stressing method, with a view to the material quality, measurements, and types of flaws to be found in different objects to be measured, not only allows the accurate control necessary to provide the correct amount of stress, but is always the key to the amount of laser holographic interference to be used in nondestructive test technologies, and to the success or failure of the technique. From the peculiar characteristics of solid fuel, our work has shown that both thermal stressing and vacuum stressing are capable of effectively carrying out nondestructive checks for viscosity flaws on layer boundaries; however, in terms of effectiveness, there are clear differences between them.

What is called thermal stressing refers to the process in which an object being checked is bombarded by thermal radiation from a heat source and increases in temperature, causing thermal expansion. Because of the fact that the thermal coefficient of conduction in areas of viscosity loss is lower than the same coefficient in areas where the viscous continuity is good, it produces a surface temperature increase in areas of viscosity loss, which is slightly greater than that in areas where surfaces have good viscous continuity. The differing phenomena related to the nature of the thermal expansion in these areas necessarily cause the production of clear localized deformities in the system of interference patterns, and these deformities in the patterns allow the discovery of flaws even in areas which have already been sealed.

This type of thermal stressing method, due to the fact that thermal stressing equipment is relatively simpler than the equipment required by other methods, is convenient, fast, and, because of this, has been used a good deal. However, thermal stressing belongs to the category of dynamic stressing. The inspection process takes place during the time when the general temperature of the surface of the object being measured is changing. Because of this, when one selects a combination of the real time holographic interference method and techniques for controlling the interference patterns, it is possible to obtain relatively good results. However, the need to combine these two techniques in order to get good results makes the difficulty of the testing even greater.

Vacuum stressing is a type of static stressing. When the air pressure inside the fuel column of solid fuel rockets is reduced from pressure P_1 to P_2, the gases which are uniformly contained within the fuel column cause an expansion which produces a transformation of the surface of the entire object. If layer boundary surfaces in the fuel column contain areas of viscosity loss, then, the gases remaining in these areas (including the component of evaporated gases) cause an expansion, and this makes areas of viscosity loss elastically transform toward the outside. A round area of viscosity loss with firm boundary conditions, causes a localized deformation (5)

$$l = K\frac{\Delta P D^4}{E H^3} \qquad (4)$$

In this equation K is the ratio coefficient. $\Delta P = P_1 - P_2$ is the difference in ambient air pressures. D is the diameter of the area of viscosity loss. E is the coefficient of elasticity for the materials. H is the depth at which the viscosity loss is positioned, which, in this paper, is the thickness of the layer involved.

Clearly the selection of vacuum stressing has the advantages listed below:

1. Due to the fact that the amount of the localized surface transformation of an area of viscosity loss 1 varies directly with the change in air pressure ΔP, it follows that the air pressure in the space (vacuum chamber) where the solid fuel column is prepared can accurately control the amount of stressing. In the crude vacuum of the vacuum chamber, it is relatively easy to carry out adjustments; moreover, it is possible to get excellent consistency.

2. Due to the fact that the whole surface of the solid fuel column is surrounded by the same ambient air pressure, it follows that all the surfaces of the fuel column are of the same geometrical form and that their mechanical strengths are all the same, so they all receive uniform stress. This causes the holographic interference pattern system of the whole body to present a clearly uniform appearance. Taking one or two round solid fuel columns as an example, if the holographic interference recording system is brought in close to the front of the fuel column, it is easy to see that the holographic interference pattern system for the whole object is a set of regular elliptical patterns as shown in Fig 1. This is exactly what makes it relatively easy to identify the localized deformations in interference patterns caused by viscosity flaws. Under comparison, the thermal stressing method is very difficult to apply evenly due to the fact that the surface of the radiation source, its shape, temperature distribution, and different in the distance between the object being irradiated and differrent points on the surface of the heat source as well as influences from many types of factors such as ambient temperature variations, etc. all contribute to making it so.

Due to these problems, it is easy to mistakenly identify a flaw or to miss one.

Making use of this peculiarity, the vacuum stressing method can also be used to check out layer viscosity strength whether or not it is uniform. In Fig 2 we see a case where the fuel column layer viscosity does not show uniform adhesion, which causes the elasticity coefficient of the boundary surface materials to vary from point to point. From (4) we can see that, after stressing, the transformation 1 also varies from point to point, and this causes waviness and shape changes in the system of holographic interference tracings.

Fig. 1.

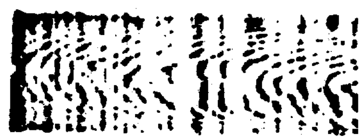

Fig. 2.

1. Fig. 1. Photograph of a Normal Holographic Interference Tracing 2. Fig 2. Typical Photograph of a Holographic Interference Tracing From a Fuel Column in Which the Surface Layer Viscosity Strengths Are Uneven

3. Another advantage of the use of vacuum stressing in solid fuel column nondestructive measurements is that it does not use any heat source. Because of this, it improves safety and reliability.

3, Vacuum Stress Laser Holographic Nondestructive Test Instruments

All instrument systems which make use of vacuum stressing in a vacuum case are prototypes. On these prototypes, their illumination and holographic transmissions all need to go through the optical glass windows which are installed on the vacuum case. This causes the two problems discussed below: (1) the scattered light caused by the illumination source on either side of the glass is recorded by the holographic interference plate, and, when it is reproduced, it creates rather strong background interference. Moreover, the holograph light coming from the object decomposes when it passes through the glass windows, with relatively great reflected losses, which results in an even more apparent attenuation. (2) In the vacuum case, during the stressing process between the two exposures, the existence of pressure differences which operate to transform the shape of the case body or the glass window produces a phase adjustment in the light waves coming from the objects. This gives rise to vacuum frequency interference tracings, which influence the resulting analysis. This is even more true for the inspection of samples of relatively large dimensions, and, in order to eliminate this type of disturbing interference, the necessary requirements in terms of the case body, the material and quality of the glass window, its strength and the method of sealing it, all make quite large demands on designers and are difficult problems to resolve.

Speaking to the problems raised above, we made plans to produce a true vacuum stressing laser holographic nondestructive test measurement instrument. Fig. 3 is an outside photograph of it. In order to simplify the apparatus, in the design of it, we took the vacuum stressing system and combined it with the holograph's anti-vibration leveling base. The diameter of the vacuum chamber is 1300mm; its length is 1500mm. We made use of its relatively large contained area and weight to install the gas charging interior vesicle in a low position, as a first level vibration reducer; moreover, in the interior of the vacuum chamber, we installed a thick steel plate as a level platform, and, under this flat platform, we also added vibration muffling rubber as a second level vibration reducer. The flat platform contains all light courses except the He-Ne laser tubes. Through the practical application of proven anti-vibration techniques, the requirements for holographic images were completely met.

Both ends of the vacuum chamber have a sealed observation window, and, because of this, the adjustment of light paths and the removal and placement of test samples are relatively easy. Through the observation windows, it is possible, during operations, to observe the holographic interference.

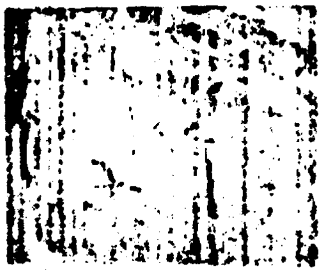

Fig. 3

This system uses a 2x-15 type vacuum pump, which is capable of taking the air pressure inside the vacuum chamber and quickly lowering it from the normal air pressure to a level of vacuum P=1. The degree of vacuum is observed and controlled from the vacuum strength meter. After experiments are completed, it is possible to use hand controls to open the seals and let the atmosphere into the chamber.

Fig. 4 is a diagram of the principles of holographic illumination light paths. After He-Ne laser sheafs pass through gate B, from the side window of the vacuum chamber, C, they are shot into the interior of the chamber. After continuing adjustments of the sheafs with the control device P, the light becomes separated into the sheaf of light coming from the object and the reference sheaf. Because the object being observed is cylindrical in shape, the sheaf of illumination light goes through expansion lens L_1 and, after it is spread out, it is fed through a cylindrical lens L_2, which causes the sheaf to be compressed laterally into a bar shape in order to raise the optical efficiency of the sheaf. The object being observed is held stationary in its place by the use of a special fork-shaped device fixed to the flat plate. All the holographic interference photographic displays appearing in this article are holographic photographs taken using this apparatus.

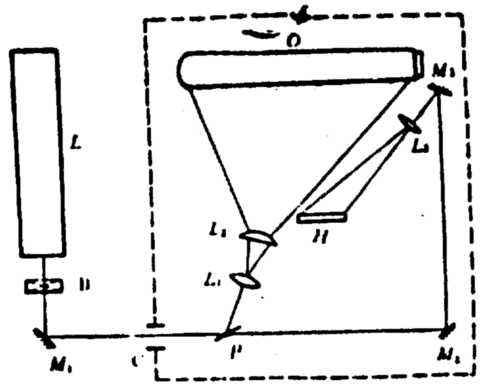

Fig 4 Diagram of Light Path Principles
(Within the Dotted Box Is the Vacuum Chamber)

L: He-Ne Laser Device B: Electromotive Shutter C: Vacuum Chamnber Side Window P: Continuous Light Adjustment Device $M_1M_2M_3$: Totally Reflective Lenses L_1, L_3: Spreading Lenses L_2: Columnar Lens H: Holographic Interference Plate O: Object Being Tested

This apparatus produced relatively good test results when used with vacuum stressing against objects appropriate for that approach, that is, such structures as vortex-shaped plates, and thin glass and steel walls. Moreover, its structure is simple, its operation is convenient, and it is capable of measuring objects of relatively large dimensions. Because of this, it has definite practical value.

Figures 5, 6, and 7 are all actual examples of tests on parts of fuel columns.

Fig 5 Normal Photograph of the Holographic Interference Patterns From Fuel Columns With Boundary Layer Artificial Viscosity Losses at √.5 and √.10.

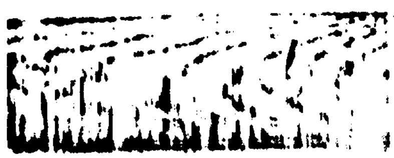

Fig 6 Normal Photograph of the Holographic Interference Patterns From a Fuel Column With Boundary Layer Man Made Viscosity Losses 5x10 and 10x10. The Surface of This Fuel Column Was Painted With White Powder, and, Because the Powder Was Not Stable, the Interference Patterns Are Deformed From Those of a Normal Body.

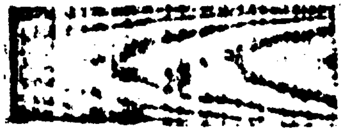

Fig 7 A Normal Photograph of the Interferecne Patterns From a Fuel Column With Uneven Boundary Layer Viscosity Strength and 20x20 Man Made Viscosity Loss Flaws

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Abstract

A new type of laser holographic vacuum stressing nondestructive testing instrument has been developed by the authors. The instrument can be used for testing comparatively large sized samples with most of its optical elements contained inside its airtight cabin. In this paper, the testing results of debond flaws for solid fuel propellant grains are given. The virtues and defects of thermal stressing and vacuum stressing are discussed.

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