Study on the Speckle Measurement of Vibration Displacement

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Abstract. The vibration displacement for any points measured has provided a series of reliable datum for the related analysis, which is a basis to do the structure design analysis. Using 3D speckle measurement can certainly obtain the vibration displacement datum in the range of measurement. The new 3D speckle measuring experiment platform verified the reliability and effectiveness by the classical measure methods has provided a new method to measure the vibration displacement.

1. Introduction

Mechanical vibration refers to the regular reciprocating motion object or particle does near the equilibrium position. The vibration quantity, a value to evaluate the vibration, can be used with the displacement, velocity or the acceleration [1]. The harm of vibration becomes prominent as the increasingly complicated modern mechanical structure or the increasing speed of movement. The use of mechanical equipment with the principle of vibration, otherwise, can produce a desired vibration. Hence, the method to prevent harm vibrations or use beneficial vibration has become a significant research interest [2].

The vibration displacement measuring one point in the structure, providing a series of reliable datum for the related analysis, is a significant research interest in displacement measurement [3]. The 3D speckle measuring system used in the experiment has measured the vibration displacement and verified the reliability and effectiveness for the measurement [4, 5].

2. The Process of Experiment

The main purpose of this experiment is to measure vibration frequency and amplitude of vibration respectively, at the time of the vibration frequency stability when the movement, after the comparative analysis of experimental results of the two verification based on feasibility of non-contact vibration measurement method of 3D digital image correlation method [6, 7, 8].

Firstly, finish the calibration of the CCD camera, and then keep the angle for the two cameras same, the pen of the inductance micrometer should be placed vertically above the sample. Last, adjust the micrometer for reducing the measurement error [9, 10].

The output signal for the signal generator frequency should be set as a stable periodic vibration signal with a value of 4Hz and the value of power amplifier voltage should be set as 8.3V(Voltage Gain) if the experiment starts. Based on the Nyquist Sampling Law, the information in the original signal can be preserved completely by the signal collected if the sampling frequency better than the highest frequency in the signal two times. So that the frequency collected in the camera image, at least, should be better than 8Hz.The image acquisition frequency should be set at 60Hz, which is 15 times as good as the original one for the vibration signal restores. What's more, the acquisition frequency for the sensor signal should be set at 100Hz.

Start the data acquisition if the above have been completed, collect the picture signal 10 times and record the instant voltage signal if the voltage signals in a stable situation.

3. Experimental Results

3.1. Measurement with the Micrometer

Take the entire voltage datum obtained in the experiment. The amplitude is represented by the first 1000 steady voltage datum's mean variance. And the sensitivity for the inductance micrometer is known as 11.945mm/V, so that the amplitude datum can be obtained, which can be seen in the Table 1, revealing that the average should be 0.335mm and the standard deviation should be 0.320. What's more, the great value of standard deviation, which means that a large deviation for each of the samples, leads to a situation that the average value in the experiment can not be used as the amplitude. Each sample is required to be compared with the data measured by the camera to ensure the accuracy of the result.

Table1. Amplitudes measured by the micrometer dial

Time	Amplitude /mm	Time	Amplitude /mm	Time	Amplitude /mm	Time	Amplitude /mm	Time	Amplitude /mm
1	0.331	3	0.324	5	0.314	7	0.297	9	0.391
2	0.330	4	0.331	6	0.308	8	0.331	10	0.392

The vibration displacement-time curve can be obtained after an analysis has been done. The periodic vibration for the steady frequency has led to the equal time for all of the vibration periods and counts the number of complete period in the vibration displacement- time curve, and finally, frequency for each vibration can be calculated in the following steps. A. Select 40 consecutive steady period datum gained in 10 measuring datum. B. Get the overall time for the 40 vibration periods in the vibration displacement-time curve obtained above. C. Calculate the vibration frequencies obtained in the experiment, which can be seen in the Table 2. D. Take the average of 10 datum as 3.992Hz representing the vibration frequency for the sample obtained with the inductance micrometer. The value of the vibration frequency provided by the excitation frequency in the experiment had been set at 4Hz, so that the theoretical vibration frequency in the experiment should be equal with the excitation frequency. Hence, the measurement error in the experiment is 0.2%.

Table 2. Frequencies measured by the micrometer dial

Time	Period	Duration /s	Frequency /Hz	Time	Period	Duration /s	Frequency /Hz
1	40	10.030	3.988	6	40	10.010	3.996
2		10.027	3.989	7		10.025	3.990
3		10.027	3.989	8		10.027	3.989
4		10.027	3.989	9		10.017	3.993
5		10.017	3.993	10		10.048	3.981

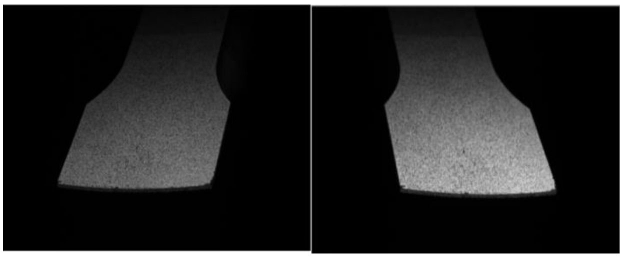
The standard deviation for the amplitude in this experiment equals to 0.064021, while the vibration frequency's standard deviation equals to 0.003974 after a error analysis for the vibration amplitudes and vibration frequencies obtained by the induction micrometer dial. A fewer value of standard deviation, standing for a fewer deviation in the experiment, reveals that the sample used in the experiment more accurate with a fewer error. The amplitude's error in this experiment becomes greater while the error of vibration frequency fewer, which reveals that, under the same excitation frequency, each of the vibration frequencies vary a few but a greater change in vibration amplitude. Thus, in the comparison with the datum measured in the image, the average of vibration frequencies can be used to compare, while the average of amplitudes can not be used but the amplitude datum of each sample shall be used to do the comparison.

3.2. Measurement with the Speckle Method

The picture acquisition frequency whose value is 60Hz had been used in the experiment. Almost 180 pictures had been collected each experiment as a great number of datum and calculations, which meant that the acquisition time remained 3 second. The image collected by the left and right camera in a condition has been shown in the Fig.1.

Divide the calculated area and set the calculated point, which can be seen in the Fig.2. Using the relating searching algorithm to calculate the displacement information needed.

Using the Software (matlab) to draw the identification schema for the datum of displacement in Y-axial with the time measured in the six experiments, which can be seen in the Fig.3. Here the datum information of first 100 sample points has been showed for a convenient observation.



Figrue 1. The image collected by the left and right camera in a condition

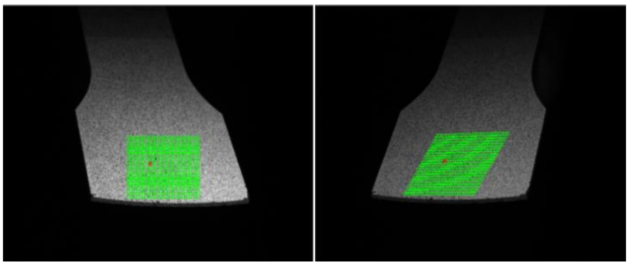


Figure 2. Image of calculated region and calculated points

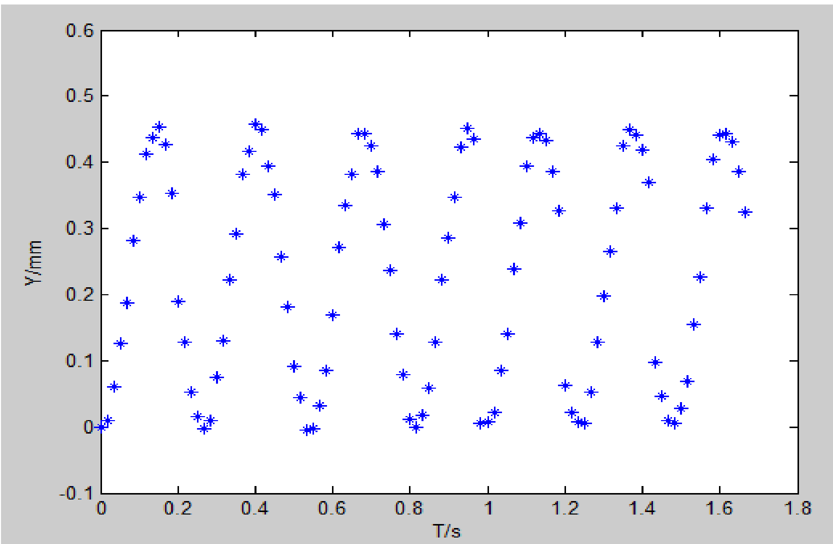


Figure 3. Figure of identification schema for the datum point

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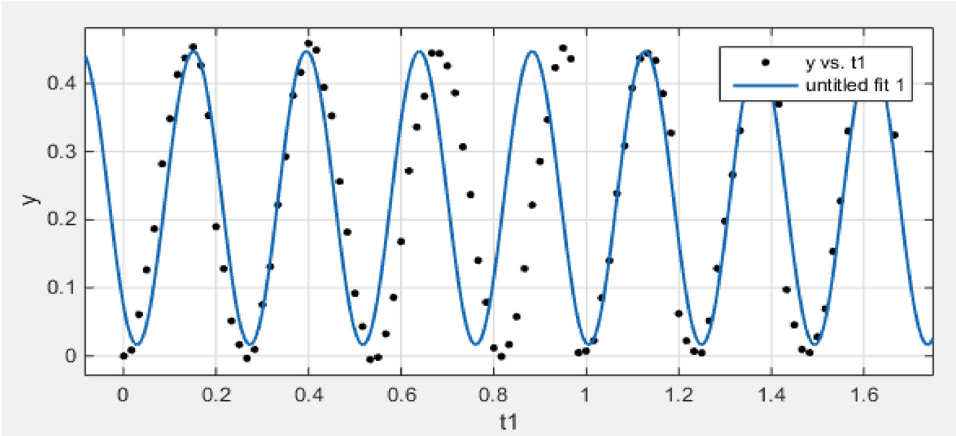

Figure 4. The Nonlinear fitting image for the y-axial displacement data changed with time

As can be seen in the Figure 3, the abscissa stands for time, unit second and the ordinate stands for the displacement of measured sample moved in the process of vibration in y-axial, unit millimeter. The absence of some points is resulted in the failure of matching algorithm in the process of acquisition, leading to the uncollected displacement datum with an end of display. Although there exists this sort of problem, it can be easy to obtain the original waveform datum from the identification schema measured before, which accords with the harmonic vibration law, preliminary revealing reliability for the 3D image related method based on the high-speed camera in the vibration measurement.

Using the Matlab to do the nonlinear fitting on the datum measured before with Least Square, as can be seen in the Fig.4.

As can be seen in the Figure 4, the abscissa stands for time, unit second and the ordinate stands for the displacement of measured sample moved in the process of vibration in y-axial, unit millimeter. The black points shown in the schema are the datum points, while the blue lines are the nonlinear fitting curve obtained by the Least Square, with a Fourier Series fitting method, accuracy bisquare. The formula 1 indicating the linear has been shown below:

$$f(t) = 0.2317 + 0.1589\cos(-25.74t)\ 0.14 . \tag{1}$$

In the fitting precision datum, SSE (The sum of squares due to error) equals 0.5658, R-square (Coefficient of determination) equals 0.7955, Adjusted R-square (Degree-of-freedom adjusted coefficient of determination) equals 0.7892 and RMSE (Root mean squared error) equals 0.07638. Normally, R-square and RMSE should be mainly observed if an analysis in fitting precision datum starts. The nearer former value approximates to 1, the greater fitting level is, while the nearer latter value approximates to 0, the fewer error is, leading to a moderate value should be selected as these two are interrelated. Although the value of R-square for the fitting curve in the experiment equals to 0.7955 keeping away with 1, RMSE approximates to 0, however. Meanwhile, with the observation of linear, although there exists some errors in the mid segment, while the fitting effect will be better if it appears in the ends. Hence, the effect of fitting linear shall be thought better basically.

According to the definition of Fourier Series, if the period of f(t) set at T, the angular frequency $\omega = \frac{2\pi}{T}$, so that the Fourier Series formula can be shown below:

$$f(t) = a_0 + \sum_{n=1}^{\infty} \left(a_n \cos n\omega t + b_n \sin n\omega t \right) . \tag{2}$$

Compared with the Formula 2, the value of ω can be calculated as 25.74. Hence, the vibration frequency should be 4.098 Hz. In comparison with the excitation frequency whose value is 4 Hz provided by the excitation system and the vibration frequency whose value is 3.992Hz measured by micrometer dial, the error percents are 2.4% and 2.6%, respectively, nearly equal to the original ones.

Do a FFT for the fitting curve in the Fig.4 and the datum measured before, the consequences have been shown in Fig.5 and Fig.6.

The datum for amplitude and vibration frequency measured in the experiment has been shown in the Table 3.

The datum shown in the Table 3 are the 10- time vibration measurements based on 3D-DIC whose average of amplitudes for 0.2409mm, standard deviation for 0.1751 and the average of vibration frequencies for 4.0743Hz with a standard deviation for 0.0187.

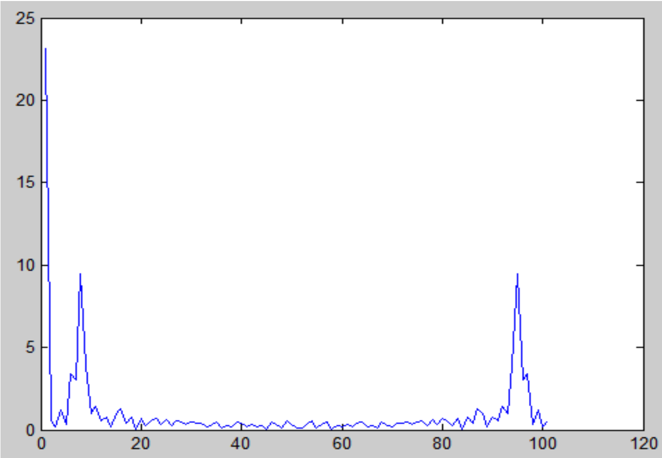

Figure 5. Waveform obtained by datum with FFT

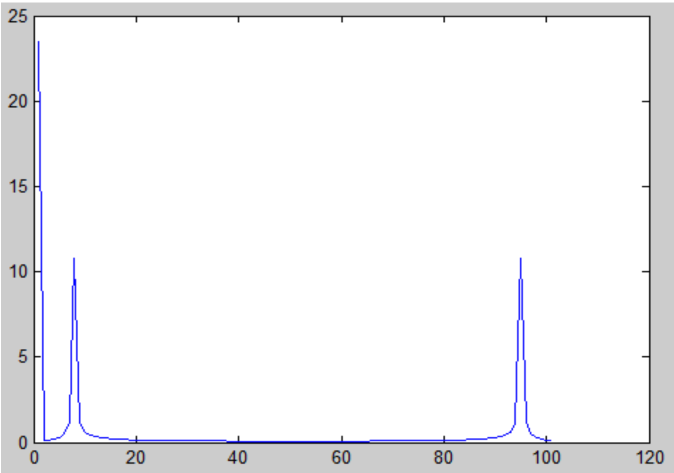

Figure 6. Waveform obtained by fitting curve with FFT

Table 3. Datum of vibration measurement based on 3D-DIC

Time	Amplitude /mm	Frequency /Hz	Time	Amplitude /mm	Frequency /Hz
1	0.243	4.058	6	0.235	4.098
2	0.239	4.049	7	0.219	4.088
3	0.229	4.053	8	0.247	4.073
4	0.233	4.058	9	0.273	4.096
5	0.224	4.091	10	0.267	4.079

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4. Conclusion

With the judgment of the datum obtained in the experiment, it is certain that there exists a greater error if the amplitude datum obtained with 3D-DIC compared with those obtained with the classical sensor, but things will be different if concerned in one axial, also, the datum collected with 3D-DIC is steadier. The time-displacement curve in Y-axial conforms completely to the harmonic vibration law with a precise collecting vibration frequency, so that the method of 3D-DIC can be considered as a good feasible way to measure vibration.

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