STRAIN/DISPLACEMENT OF A CARABINER VIA HOLOGRAPHIC INTERFEROMETRY

A double exposed reflection hologram and interferometry will be used to analyze the structural integrity of a carabiner. The first exposure will depict the carabiner unstressed, and the second will illustrate the carabiner under stress. After this, the carabiner will be broken and then compared with a developed hologram. The breaking strength will be determined using this method. A double exposed hologram of a control block – which moves approximately one micrometer – will be used to find a relationship between the amount of displacement and the weight applied to the carabiner. A hologram will then be made using the weight needed to move the carabiner one-micrometer to verify the relationship. Once the theory is validated, another carabiner, of the same model with little use, will be used as a test piece. Another double exposed hologram will then be taken of the new carabiner. Next the carabiner will be cycled approximate 500,000 times with a two Kilo-Newton load for duration of one week. Then one more double exposed hologram will be made after the cycles are completed. Once the holograms are developed, the two will be compared thus showing any changes in structural integrity if any are present. If changes in structural integrity are observed, a guide to determine if the carabiner being tested should be retired will be recommended.

MICHAEL A. WALK

I am a Graduate from Rock Bridge High School and the Columbia Area Career Center. I have received the rank of Eagle Scout and continue to participate in the Boy Scouts of America. I have been published in The International Society of Optical Engineering (SPIE) Annual Convention's proceeding in 2000. I am a member of the National Speleological Society and our local affiliate, Chouteau Grotto, and have received training through the National Cave Rescue Commission.

Strain/displacement of a carabiner via interferometry

Michael A. Walk

ABSTRACT

A double exposed reflection hologram and interferometry will be used to analyze the structural integrity of a carabiner. The first exposure will depict the carabiner unstressed, and the second will illustrate the carabiner under stress. After this, the carabiner will be broken and then compared with a developed hologram. The breaking strength will be determined using this method. A double exposed hologram of a control block - which moves approximately one micrometer – will be used to find a relationship between the amount of displacement and the weight applied to the carabiner. A hologram will then be made using the weight needed to move the carabiner one-micrometer to verify the relationship. Once the theory is validated, another carabiner, of the same model with little use, will be used as a test piece. Another double exposed hologram will then be taken of the new carabiner. Next the carabiner will be cycled approximately 500,000 times with a two Kilo-Newton load for duration of one week. Then one more double exposed hologram will be made after the cycles are completed. Once the holograms are developed, the two will be compared thus showing any changes in structural integrity if any are present. If changes in structural integrity are observed, a guide to determine if the carabiner being tested should be retired will be recommended.

Keywords: Displacement/Strain measurement, industry, manufacturing, quality control

1. INTRODUCTION

A double exposed reflection hologram and interferometry will be used to analyze the structural integrity of a carabiner. Carabiners are used in many high-risk activities such as spelunking, rock climbing, and rescues. The carabiner being tested has a breaking strength of 24 kilo-Newton. Current testing of new models involves the destruction of hundreds or thousands of carabiners. By finding new ways to test these carabiners, many companies in the rescue equipment manufacturing businesses can possibly save money.

2. THEORY

Interferometry can be used to calculate how much an object has changed. By adding weight to induce interference on a single beam reflection hologram, the displacement can be calculated. The amount of movement of a hologram can be measured by

$$\Delta Y = N(\lambda/2), \tag{1}$$

where the difference in the Y-axis equals the number of bands (figure 1) times half the wavelength of the laser used. Thus, one light and one dark line equals one-half a wavelength.

Fig. 1

3. EXPERIMENT

3.1 Experimental Set Up

Figure 2 shows the use of a standard Denisyuk holographic system, which was used to expose the holograms. A 30 mW. Helium-Neon laser was used to expose the PFG-03M (red sensitive – 633nm.) holographic plates.

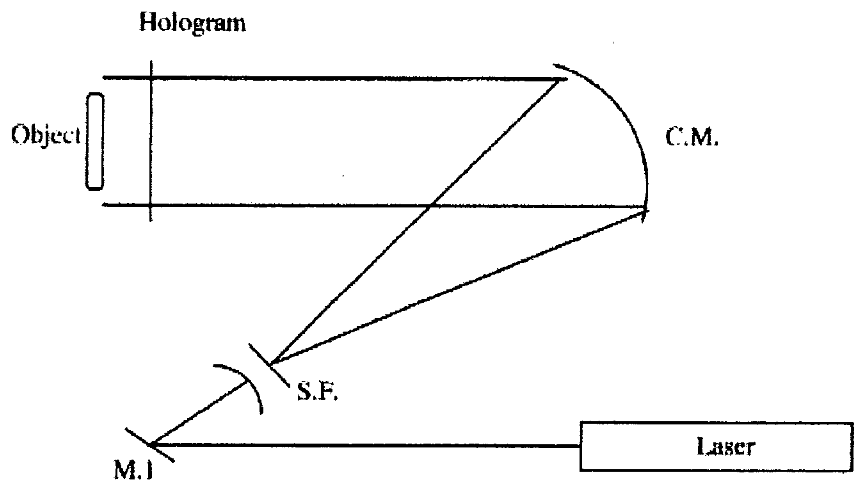


Fig. 2. Denisyuk hologram set-up. Laser beam reflects off a first surface mirror (M.1) through a spatial filter (S.F.) and reflects off a collimating mirror (C.M.). Spatial Filter consists of a 20x-microscope objective and a 15 micron pinhole.

Figure 3 shows how the carabiner was held in place by a 15:1 lever, which was mounted to the table.

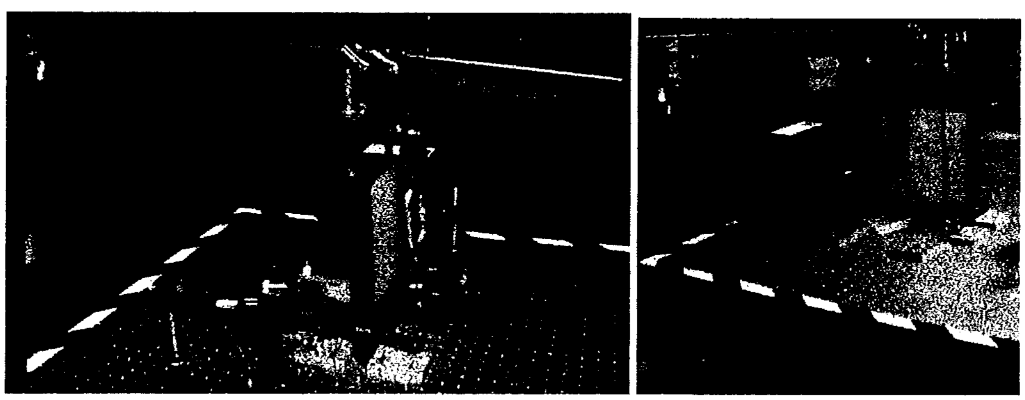


Fig. 3

Figure 4 illustrates the control block that was made from aluminum with the dimensions of one and one half inches tall by two inches wide by one inch deep.

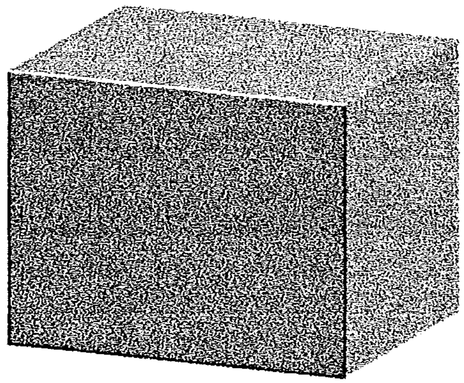


Fig.4

3.2 Calculating the Exposure Time

The exposure time can be calculated by finding the irradiance of the expanded beam at the holographic plate, as shown by

$$E = \frac{P}{A} \qquad (2)$$

where the irradiance equals the power measured, in Joules per second, divided by the area of the detector head, measured in centimeters. The conversion from watts to Joules per second is

$$W = J / sec. \qquad (3)$$

where one watt equals one Joule per second. The area of the detector can be calculated by

$$A = \pi r^2 \qquad (4)$$

where the area of a circular detector is equal to pi times the radius of the detector squared, or

$$A = \frac{\lambda d}{4} \qquad (5)$$

where the area of the circular detector is equal to the quantity of pi times the diameter of the detector divided by four. Once the irradiance has been calculated, the time can be calculated by

$$T = \frac{S}{E} \qquad (6)$$

where the time required to expose the holographic plate is equal to the film sensitivity divided by the calculated irradiance.

3.3 Cycling the Carabiner

Figure 5 shows the sinusoidal waveform, which fatigue testing is typically done with. The maximum force applied to the carabiner is 2000 Newton's of force and the minimum setting for the sinusoidal wave is typically ten percent of the maximum load. The time duration for one cycle is two cycles per second or two-Hertz. The carabiner was cycled for approximately 500,000 cycles.

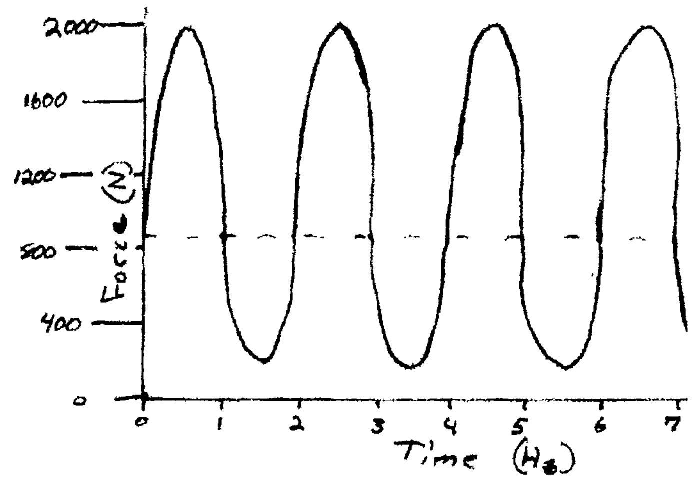


Fig. 5

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Experimental Set Up

The use of a Denisyuk holographic set up as opposed to another holographic system was the simplicity of the set up. Due to the time frame and equipment availability, a single-beam white-light reflection hologram was the best option for use. There was a problem with the power ratios, which the reference beam should be about twice the object beam; this was solved with an opaque glass screen behind the carabiner. The opaque screen caused more illumination, thus making a brighter hologram.

4.2 Experiment

The first series of holograms that were taken were at an increasing weight as shown by figure 6.

Hologram Number	Weight Used	Amount of stress on carabiner
1	0 pounds	0 pounds
2	1.1 pounds	16.5 pounds
3	2.2 pounds	33 pounds
4	3.3 pounds	49.5 pounds
5	4 pounds	60 pounds
6	5.1 pounds	76.5 pounds
7	6.2 pounds	93 pounds
8	7.3 pounds	109.5 pounds
9	8.4 pounds	126 pounds
10	9.5 pounds	142.5 pounds
11	10 pounds	150 pounds

Fig. 6

150 pounds of stress is all that was used due to the possibility of deforming the table. The interference banding was induced by applying and additional 150 grams of stress between exposures. Once the first series of holograms were

taken, the carabiner was cycled 500,100 times at a two-kilo-Newton load. Instead of a perfect sinusoidal waveform, the maximum load showed a secondary spike. (Figure 7)

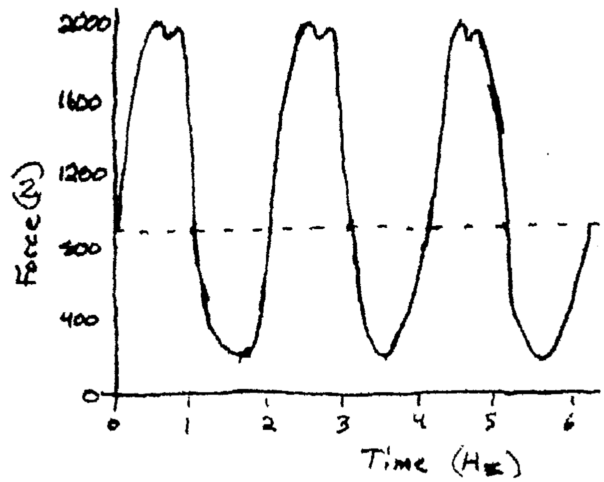
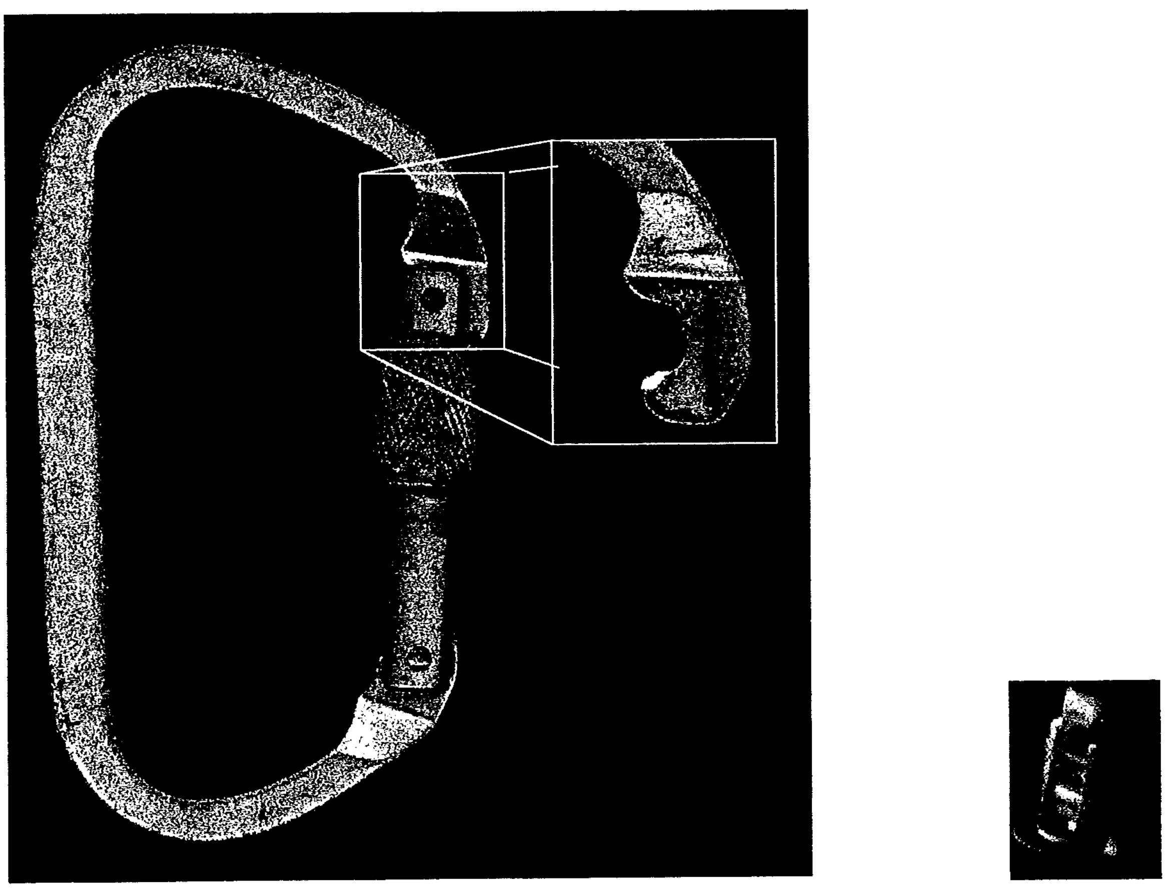


Fig.7

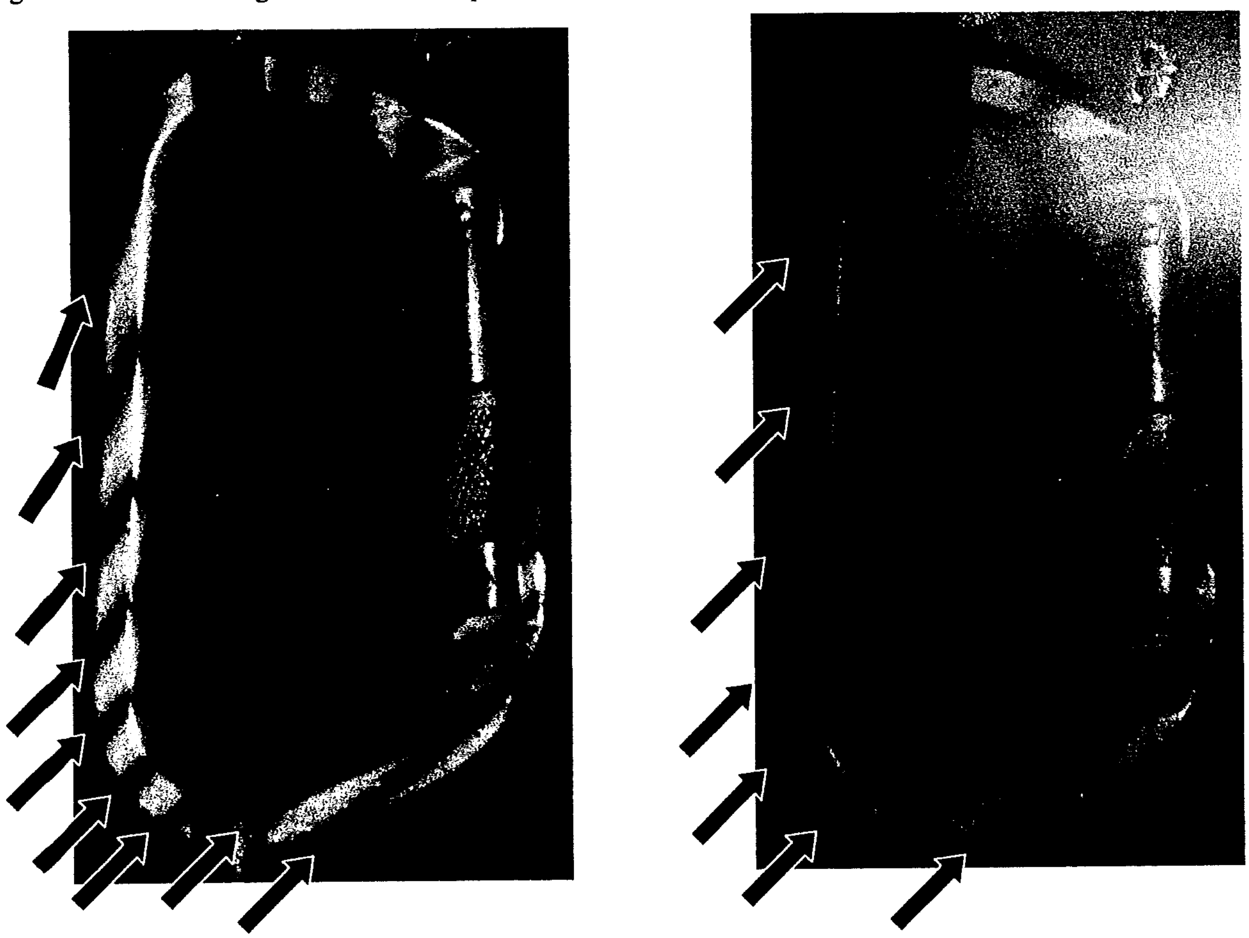
The secondary spike is due to the pin of the gate of the carabiner striking the catch of the carabiner. (Figure 8)



1. (a) (b)

Fig. 8 The catch of the carabiner is shown (a) and the pin is in the catch (b).

The maximum load varied from 2084 Newton's to 2012 Newton's. This variation was a steady decrease in Newton's. The minimum load varied from 200.3 Newton's to 193.2 Newton's. Due to the lack of strain on the carabiner, the minimum load varied seldom. During the cycling, the gate was rubbing against the catch of the carabiner causing a squeaking sound to be made and a white powder residue to form. After the cycling of the carabiner, the second set of holograms was shot at the same weights shown in figure 6. Pictures of some of the holograms can be seen in figure 9. The arrows point out the interference fringes and direction of banding.



(a) (b)

Fig. 9 Hologram with 150 pounds of stress before cycling (a) and after cycling. (b)

4.2 Calculating Movement

Figure 10 shows the number of bands on each hologram.

Hologram Number	Number of Bands on Set Number 1 (Before Cycling)	Number of Bands on Set Number 2 (After Cycling)
1	3	3
2	2	4
3	2	2
4	3	1
5	5	3
6	2	3
7	4	3
8	3	2
9	3	2
10	4	2
11	8	7

Fig. 10

Figure 11 better demonstrates figure 10 with the use of a graph.

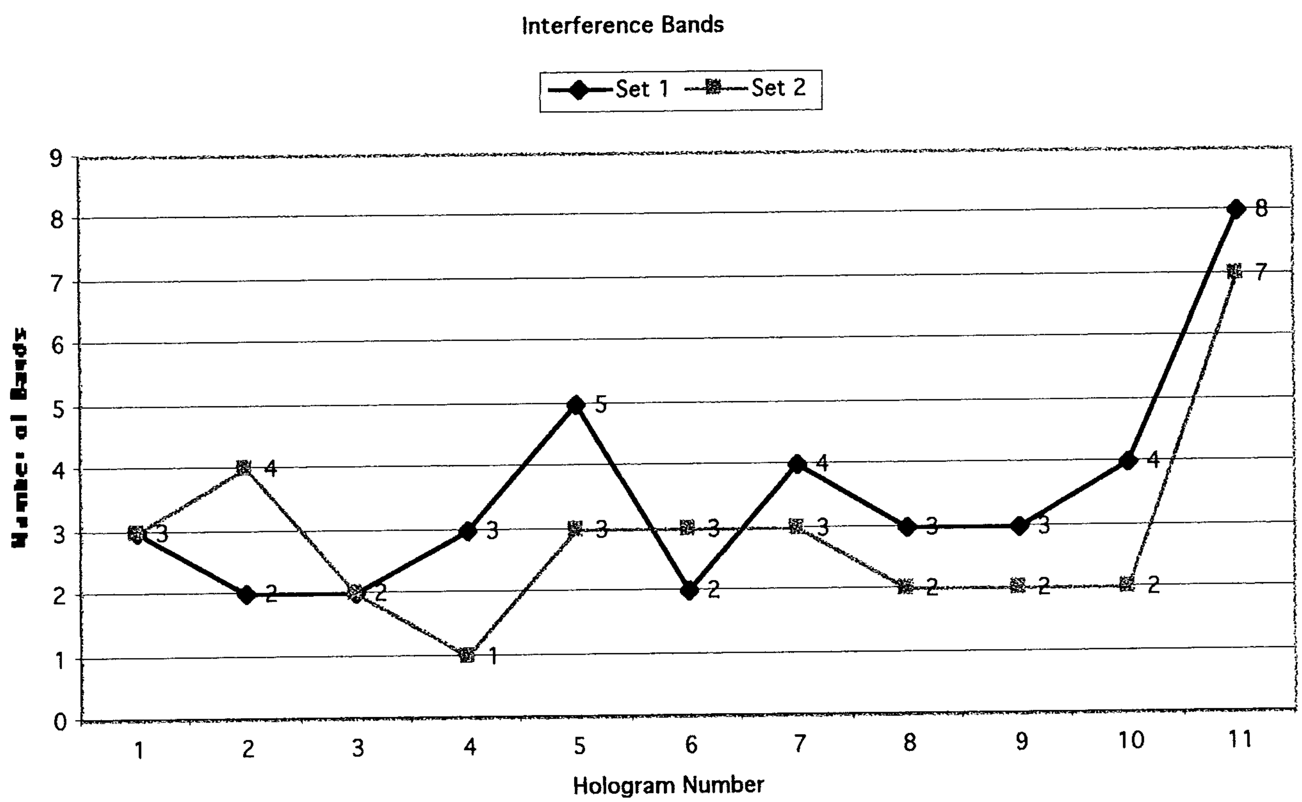


Fig. 11

By using equation 1, the amount of movement can be calculated. The wavelength of the Helium-Neon laser is 632.8 nm. Figure 12 shows the calculated amount of movement of the carabiner.

Hologram Number	Amount of Movement on Set Number 1 (Before Cycling)	Amount of Movement on Set Number 2 (After Cycling)
1	949.2 nm	949.2 nm
2	632.8 nm	1265.6 nm
3	632.8 nm	632.8 nm
4	949.2 nm	316.4 nm
5	1582 nm	949.2 nm
6	949.2 nm	949.2 nm
7	1265.6 nm	949.2 nm
8	949.2 nm	632.8 nm
9	949.2 nm	632.8 nm
10	1265.6 nm	632.8 nm
11	2531.2 nm	2214.8 nm

Fig. 12

Figure 13 better illustrates figure 12 in the form of a graph.

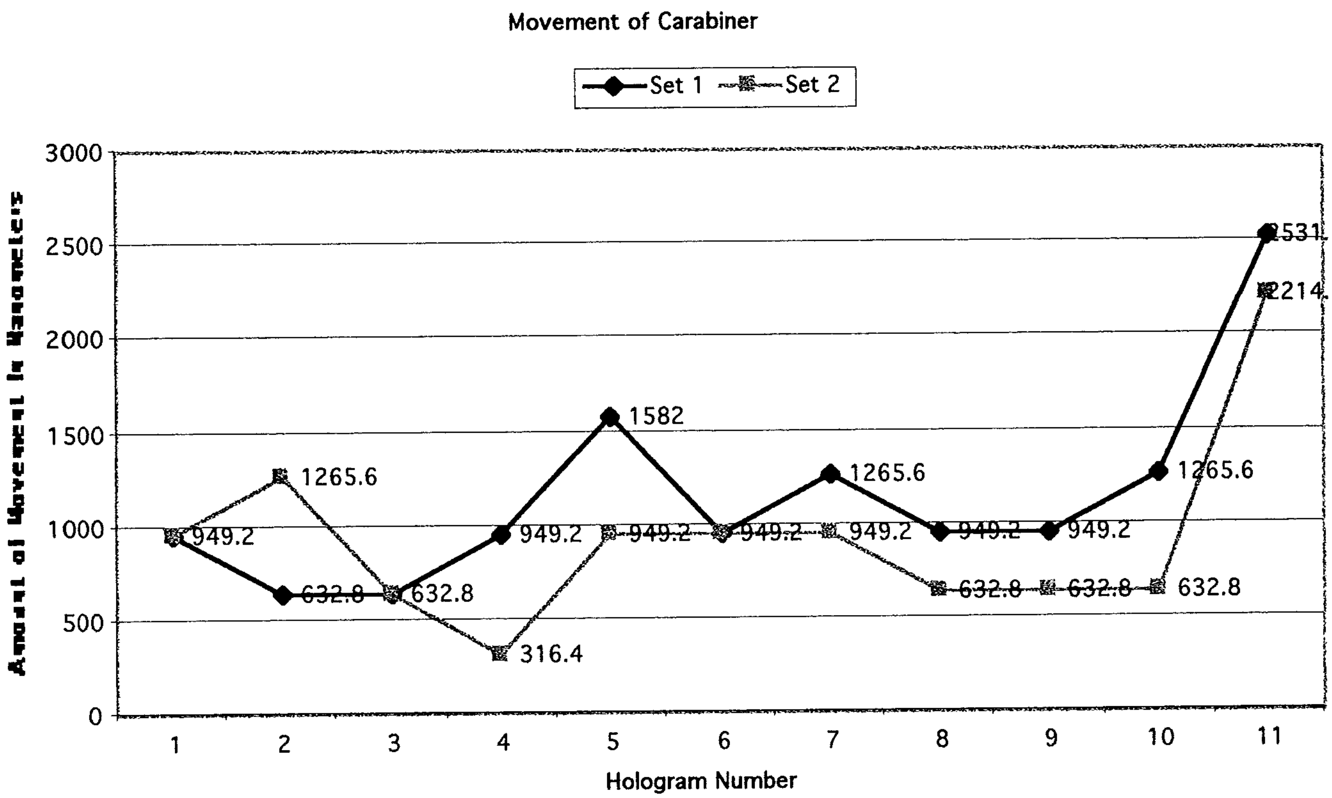


Fig. 13

5. CONCLUSIONS

From 7.3 pounds to 10 pounds of weight, there appears to be a constant exponential increase in movement by the carabiner. Due to the inconsistency at low stress levels, determining the breaking strength was not possible. This method of testing does appear to be able to give the results required to predict the breaking point.

References

1. Daniel Malacara, *Optical Shop Testing,* 1.1, 2-3, Wiley-Interscience Publication, 1992
2. Graham Saxby, *Practical Holography,* 23, 389-408, Prentice Hall, 1994
3. J. S. Darlin, M. P. Kothiyal, R. S. Sirohi, "Hybrid wedge plate-grating interferometer collimation testing" Optical Engineering, **vol. 37 num. 5**, 1593-1597, 1998
4. Stanislav Urgela, "Grading of wooden plates for musical instrument making by means of holographic interferometry" Optical Engineering, **vol. 37 num. 7**, 2108-2118, 1998
5. Tung H. Jeong, Professor of Physics, Lake Forrest College, Lake Forrest Illinois,60045
6. Dr. William Carson, Lapierre Professor, University of Missouri-Columbia, Columbia Missouri, 65211
7. Pearl John, Holography/Laser Technology Instructor, Columbia Area Career Center, Columbia, Missouri, 65203
8. Richard A. Shanks, Photoncs/Laser Technology Instructor, Columbia Area Career Center, Columbia, Missouri, 65203