A SINGLE LOADING DIRECTION FOR FATIGUE LIFE PREDICTION AND TESTING OF HANDLEBARS FOR OFF- ROAD BICYCLES

Sean P. McKenna, Michael R. Hill, Maury L. Hull

Department of Mechanical Engineering
University of California at Davis
Davis, CA 95616

INTRODUCTION

To prevent structural failure of components such as handlebars, which break regularly in the off-road environment [1, 2], one quantity that is important to determine is the direction of loading that produces the most fatigue damage independent of the effects of assembly of the handlebar with the stem. Hereafter this quantity is called the direction of maximum damage. This direction is important to determine because the prediction of fatigue life and fatigue testing of the handlebar are complicated by the variable-direction and variable-amplitude loading that the handlebar experiences. If the direction of maximum damage were known, then it could be used in single-loading axis predictions of high cycle fatigue life for a particular stem/handlebar assembly and also in fatigue testing for product qualification. Thus the objectives of this work were 1) to devise a method for determining the single direction of loading which causes the maximum damage, and 2) to determine the direction of maximum damage for an existing database of handlebar loads measured during off-road cycling [3].

METHODS

The conditions of the downhill ride from which the database was obtained were typical of common conditions of off-road cycling. The seven subjects were experienced recreational riders who weighed on average 75.6 kg and were 180 cm tall. The terrain consisted of a straight trail with an 8% downhill grade containing rocks, ruts, and washouts. Because the loads applied by the hands to each side of the handlebar were recorded for two rides of each rider, a total of 28 (7 riders x 2 rides x 2 sides of the handlebar) different 30-second trials were available from this database.

The commercially available handlebar modeled in this study was 580 mm in length, had a 6-degree bend, and was manufactured from 6061-T6 aluminum.

To compute the direction of maximum damage, several calculations similar to a variable amplitude load fatigue life prediction were made. First, the stresses developed in the handlebar as a result of forces from the riders' hands were determined using basic beam theory. Because the loading measured during the downhill riding was in two directions along the X- and Z-axes (Figure 1), the stress around the outer surface of the handlebar was calculated from:

$$s(t, q_b) = -\frac{l r_o}{I}\left[F_z(t)\sin(q_b) + F_x(t)\cos(q_b)\right] \qquad (1)$$

where $F_x(t)$ and $F_z(t)$ are force components as a function of time t from the loading database along the X and Z-axes respectively, l is the length of the cantilever measured from the center of the riders hands to the edge of the handlebar clamp, r_o is the outer radius of the handlebar, I is the moment of inertia, and F is the applied load. q_b is the angle from the X-axis as indicated in Figure 1 and ranged from 0° to 360° in 1° increments.

At each 1° increment around the handlebar, the stresses calculated from Eq. 1 were input to a cycle counting and cumulative damage computation. The stresses from each of the 28 trials were analyzed to determine a set of stress amplitudes and their corresponding mean stresses using rainflow counting. Next, for each pair of stress amplitude, s_a, and corresponding mean stress, s_m, the Walker equation was used to determine an equivalent zero-to-tension stress, s_{eq}, using:

$$R = \frac{s_{\min}}{s_{\max}} = \frac{s_a - s_m}{s_a + s_m} \qquad (2)$$

$$s_{eq} = s_{\max}(1-R)^{0.63} \qquad (3)$$

where R is the stress ratio and s_{min} and s_{max} are the maximum and minimum stresses for a given cycle. For each value of the equivalent stress, the corresponding fatigue life for constant amplitude loading was determined from:

$$N_f = \left(\frac{s_{eq}}{871.5}\right)^{-9.84} \qquad (4)$$

where N_f is the number of cycles to failure for s_{eq}, which is given in MPa. Using Miner's rule, the damage d was calculated for each pair of stress amplitude and mean stress using:

$$d = \frac{1}{N_f} \qquad (5)$$

where d is the damage associated with a given N_f.

For a particular downhill trial, the cumulative damage D at a specified location was the sum of all the damages d for the set of stress amplitude and mean stress pairs. The point of maximum damage for each trial was the location of the largest damage found among all 360 points around the bar. The direction of maximum damage was the direction along which a load would be applied to have the maximum bending stress occur at the point of maximum damage.

RESULTS

For a particular trial, the damage varied around the handlebar (Figure 2). Although the RMS resultant force magnitudes were similar, the maximum cumulative damage generated from each trial varied by six orders of magnitude. Trial 8 produced the most damage, trial 24 produced the least damage, and trial 26 produced the median for all trials. Despite the differences in the amount of damage, the patterns for the distribution of damage around the circumference of the handlebar were comparable for these trials. The regions with very small damage were those regions near the neutral axis of bending (i.e. ± 90° from the locations with the largest damage).

The point of maximum damage varied from trial to trial. Because the median of these angles was 142° and the mean and mode were comparable to the median, the median was used to define the overall point of maximum damage. To create a tensile stress in bending at an angle of 142°, a load would have to be applied at 322° (322° = 142°+180°). Thus, 322° was found to be the direction of maximum damage.

DISCUSSION

Knowing the direction of maximum damage in conjunction with the effects of assembly would enable a design engineer to determine the region of highest stress on the handlebar for a particular stem/handlebar assembly. Because the direction of maximum damage is independent of the stem, it can be used for design and testing of any stem/handlebar assembly. Note however that the region of highest stress for a particular stem/handlebar assembly will not in general coincide with the point of maximum damage determined herein. Both assembly stresses due to tightening of the handlebar stem clamp and stress concentration at the stem clamp/handlebar junction may act in concert to shift the point of maximum damage for a particular stem/handlebar assembly. Consequently, to determine the point of maximum damage for a particular stem/handlebar assembly analytically, the assembly stress and stress concentration would have to be determined and incorporated into the damage calculations.

Although the direction of maximum damage cannot be used to determine the point of maximum damage for a particular stem/handlebar assembly analytically without additional information concerning the effects of assembly, it can be used for single-axis mechanical testing of stem/handlebar assemblies. In the case of testing, the effects of assembly stress and stress concentration are inherent to the assembly and therefore these effects will be reflected in the failure process. Consequently the point of maximum damage could be determined experimentally for a particular stem/handlebar assembly by loading along the direction of maximum damage determined herein and observing the location of fatigue crack initiation.

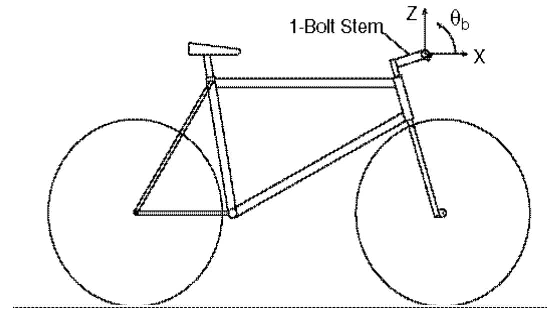

Figure 1. Coordinate system.

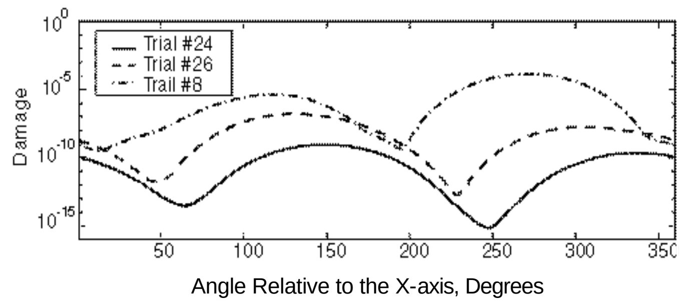

Figure 2. Plot of damage as a function of angle relative to the X-axis for three trials of the downhill ride database.

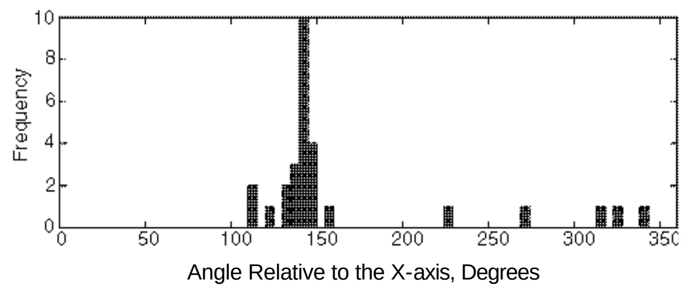

Figure 3. Histogram of the point of maximum damage for all 28 trials from the downhill ride database.

ACKNOWLEDGEMENT

We thank Answer Products and Cannondale Bicycle Corporation for providing the resources for this project.

REFERENCES

1. Specialized Announces Bike Brake, Handlebar Recall, U.S. Consumer Product Safety Commission, Office of Information and Public Affairs, Release # 95-155, 1995.
2. Trek Bicycle Corporation Announces Recall of Road Bikes and Handlebar Stems, U.S. Consumer Product Safety Commission, Office of Information and Public Affairs, Release # 00-192, 2000.
3. De Lorenzo DS, Hull ML. Quantification of structural loading during off-road cycling. Journal of Biomechanical Engineering 1999; 121(4):399-405.