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The design and implementation of an ultra high cycle fatigue testing machine

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1 Introduction

1.1 Changes as recommended by Examiner 1

The changes suggested by the first external examiner are copied here and the solutions to the recommended change are subsequently described:

1. In more than one occasion the word **in** is written **is** and vice-versa – see for example second line of p.33. A quick revision of the text should be made to avoid this and other spelling errors.

Pg. 33 changed "is" to "in" in first paragraph. The updated line ends are follows: "…10^6 cycles **in** a short period of time." An electronic search for other errors of this sort did not reveal any.

2. Some graphs must be improved. Especially in the literature review. For example in figure 2-7 all the data is unreadable –p. 13. In previous p. 12 figure 2-6 all units are missing.
    a. Pg. 12 added labels to figure 2-6
    b. Improved figure 2-7 (page 13) to have larger x and y axis labels and ticks. The labels and legend text were also improved to add clarity to the figure.
    c. Changed figure 2-18 page 22 to have more readable axis data.
3. Some references are missing. For example, referring the Haibach's suggestion on the use of the Basquin's law, to describe the materials data in the UHCF region. No reference is given regarding this word see p.12
    a. Added reference [34] to page 79 of the reference section to allow for referencing on page 12.
    b. Added reference [34] on page 12, 3rd line from the bottom.
4. The final design drawings are not completed and a cost analysis is missing. A final assembly design, containing all parts of the final machine must be included (not only the support), especially regarding the last version designed. This is important since this thesis has a great component of design.
    a. Add a full exploded drawing of the final rig in appendix E
        i. Added appendix E1 on page 170 to 171.
        ii. Changed heading for chapter E2 from "Assembly" to "Support Assembly"
        iii. Added appendix E7, E8, and E9 for the AL7075 specimen (pg. 177), AL2024 specimen (pg. 178) and AL7075 horn (pg. 179) respectively.
    b. Added reference to drawing in appendix E1 on page 64 under image 4-38. The final sentence was also restructured to read: "The initial rig setup is run upside down as this allows for the tripod of the laser vibrometer to be used without requiring additional mountings or mirroring. A detailed list of components excluding the laser is indicated in Appendix E.1 together with a schematic of the full component configuration for the final Mark 3 system."
    c. Added cost analysis as appendix J and a reference to appendix J was added to page 68 as section 5.3. All sections after this section shift in number.
5. It is not clear if the necessary calculations were performed regarding the resonance conditions and the vibration transfer between the rig and the ground.

A section was added for the laser measurement of the rig vibration during operation on page 58 to 61 under the section heading "Verification of Rig Resonance". The changes made to clarify this comment, was too include a detailed description of where laser vibrometer displacements were measured during operation of the Piezo electric actuator operating at 70% to verify the rig vibration. Further results are added in the form of three additional figures, (4-31 to 4-33) for the measured locations to indicate that the displacements of the support are negligible and will not affect the final measured results. A modal analysis image is also added to page 61 (figure 4-34) to indicate the first bending mode of the upper support plate is at 8Hz. Thus there is sufficient separation of frequencies to negate excitation of the upper support during operation at 20 kHz.

1.2 Changes as recommended by Examiner 2

The changes suggested by the second external examiner are copied here and the solutions to the recommended changes are subsequently described.

1. Page 16-"the effect of the frequency…" Is this true for all frequencies or just 100Hz?

This is valid for all low vs. high frequencies dependant on the crystalline structure of the material. No addition to the report is made for this comment as 100Hz is just the typical operating frequency for servo-hydraulic fatigue testing machines and a statement that this is true for all frequencies other than 100Hz cannot be substantiated with literature references.

2. Page 19 – "…Should have little effect…" How can you support this statement?

Add line on page 19 to state: "Overall the effect of the frequency of testing should have little effect on the fatigue results for the materials being tested in this dissertation since both specimens types will be aluminium with a FCC crystalline structure which has been shown to not be affected by the frequency of testing; however this should be validated for each material"

3. Page 19 – "...FCC aluminium was not affected by the loading frequencies…" Is this true for all frequencies?
    a. Add line on page 19 to state: "Both Papakyriacou and Mayer did find that FCC aluminium was not affected by the loading frequency when comparing 100Hz fatigue testing to UHCF testing at 20 kHz. This bodes well for the validation tests of this dissertation which will be based on AL2024 and AL7075.
    b. Papakyriacou only performed a comparison of 100Hz to 20 kHz hence this assumption is only valid for similar ranges.
4. Page 20 – "...Copper as the major alloying element…" add chemical compositions.

Chemical composition added on page 20 "The chemical composition is typically: 0.50%-Si, 0.50%-Fe, 4.9%-Cu, 0.90%-Mn, 1.8%-Mg, 0.10%-Cr, 0.25%-Zn, 0.15%-Ti and 0.15%-Others. The rest of the weight percentage is aluminium."

5. Page 21 – enlarge figure 2-17 and P=2780kg/m^3 P is not the correct symbol.

Enlarged figure and change P to Greek letter rho.

6. Page 28 – "...zinc as the major alloying element…" add chemical compositions.

Chemical composition added on page 20 “The chemical composition is typically: 0.40%-Si, 0.50%-Fe, 2.0%-Cu, 0.30%-Mn, 2.90%-Mg, 0.28%-Cr, 6.10%-Zn, 0.20%-Ti and 0.15%-Other. The rest of the weight percentage is aluminium.”

7. Page 31 –“different skill levels...” The test is performed by a machine

First bullet has been removed from page 31. Yes the test is performed by a machine but the setup and insurance that the test is completed in the right environmental conditions are based on the person running the test.

8. Page 31 –“Corrosive and aggressive...”

To improve clarification the following example is added: “For example, humidity will play a role in a fatigue test which is subject to long test periods if the laboratory does not have a controlled environment which is not always the case.”

9. Page 33–“…able to produce repeatable and reliable…” How are you planning to verify the repeatability and reliability of the tests over time?

This will be verified through testing to ensure for similar loading the fatigue lives are in the same ball park. Nothing added to report.

10. Page 34–“…specimens could be pre-fatigued…” Pre-fatigued? Maybe you mean damaged? Or pre-cracked? Not clear.

Only pre-fatigue word usage was found on page 44. This was elaborated on with the following addition to page 44 –“This could occur during turning as tool loading may induce cracks or damage within the specimen.”

11. Page 46–“indicated in 0…”

Corrected to indicated appendix E

12. Page 53–“…their average has a negligible effect on…” if there are spike stresses, they are causing retardation effects on the crack! The applied signal implies a very different time history compared to a constant amplitude signal. The explanation given about the negligible effects is weak and a more deep understanding should be provided.

The following changes were made and added to page 53: “If these spikes are indeed real, then this would mean that the strain gauges would see some high over-stresses which could cause them to fail prematurely, however failure was not evident in testing. These spikes would also cause crack retardation which may improve fatigue life data. However, since these fatigue tests are only run till crack initiation this will not pose a problem in the final data.”

13. Page 56–“…was defined as…” The reported equation and equation on the graph are not the same.

Updated equation in body to match graph equation “$y = 6.8239x$".

14. Page 58–"…was defined as…" The reported equation and equation on the graph are not the same.

Updated equation in body to match graph equation "$y = -1.4388x$".

15. Page 74–"…allowable for future design." Fatigue in composites is a quite different process from fatigue in metals. You have to demonstrate that the design would work, before starting the tests.

Due to updates from the previous examiner this issues is actually on page 77 in the Conclusions and Recommendation section. The following was added to page 77 to clarify:" It is understood that fatigue in composites is completely different to that in metals and to actually get a resonant coupon in composites will be the most difficult task. Also, during fatigue, cracks will be initiated and retarded within the composite matrix which will change the resonance of the tested specimen. This effect needs to be tracked to maintain a 20 kHz operating range or the operating range will need to be widened."