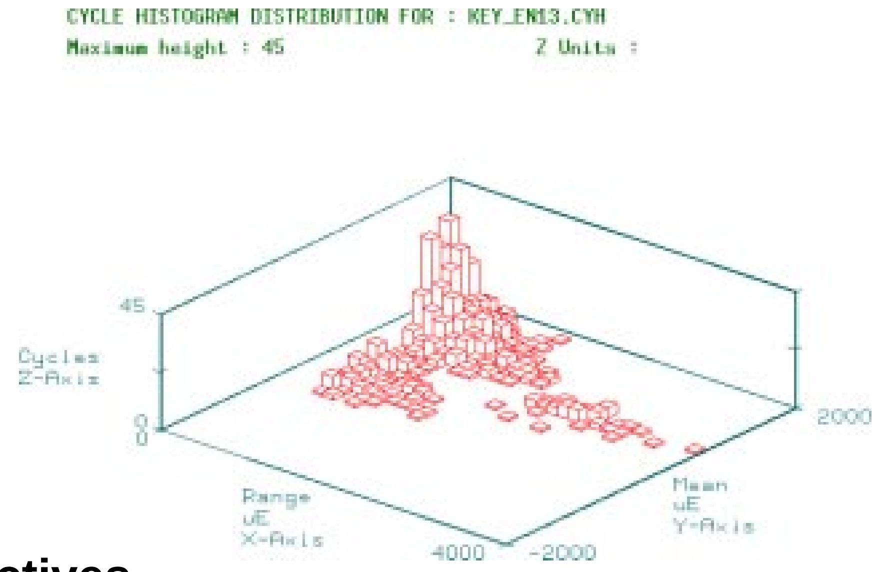
LESSON 5

Critical Initiation Analysis of the Keyhole Specimen



Objectives

- To calculate the life to crack initiation of a fatigue crack for a component made from MANTEN undergoing a "transmission" loading whose peak load is 15.87 KN.
- To investigate the effect of surface finish on the life to initiation by analyzing the effect of machining marks around the notch.
- To gain appreciation of the effect of different mean stress correction methods on fatigue life.
- To make a comparison between MANTEN and RQC100 under the above loading conditions.

Problem Description:

This exercise is concerned with the crack initiation fatigue analysis of a simple “keyhole” specimen, shown in FIGURE 5.

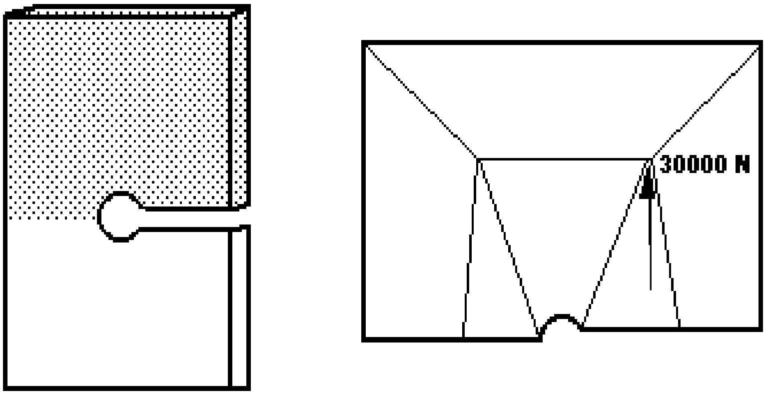


FIGURE 5. Keyhole Geometry and Loading.

The loading location and magnitude in Newtons is also shown. Two different materials were used for this component, MANTEN and RQC100. These materials were tested according to ASTM E606 using a special test specimen under strain control to obtain cyclic stress strain and strain-life data. The test specimen was polished, and the surface was untreated. A special regression analysis was performed on the new data to calculate the local strain parameters listed in Table 5-2.

The specimen was then loaded with 3 random time histories, corresponding to typical histories for transmission, suspension and bracket components at different load levels. In this exercise, however, you will only be considering the transmission time history.

A finite element analysis was performed with a static loading of 30kN and the results stored under the jobname **key.** For proper execution of this exercise, make sure you are in the **ex05** directory of your PAT318 account. Also you must translate the file **key.txt** to **key.res** using RESTXT as with previous exercises.

Table 5-2 Crack Initiation Properties.

Material Properties	MANTEN	RQC100
Fatigue strength coefficient, Sf' (MPa)	917	1158
Fatigue strength exponent, b	-0.095	-0.075
Fatigue ductility coefficient, Ef'	0.26	1.06
Fatigue ductility exponent, c	-0.47	-0.75
Cyclic strain hardening exponent, n'	0.19	0.1
Cyclic strain coefficient, k' (MPa)	1103	1151
Standard error, SE	0	0
Young's Modulus, E (MPa)	2.034E5	2.034E5
UTS (MPa)	552	827

Exercise Procedure

Step 1 Using PATRAN

Enter PATRAN, and read **key.out** neutral file.

p3 Start P3/PATRAN from the UNIX prompt.

File/New Database Open the File pull-down menu. Select New Database from the pull-down menu.

key Enter the name key in the *New Database Name* databox.

OK Click on the OK button. When the New Model Preferences form appears, change the preference to P3/FEA, click on the OK button to close the form.

File/Import In the Neutral Files listbox, select the file key.out. Click on the OK button to begin the model import operation. Acknowledge the Question form application NEUTLOD.

Look briefly at the stress results as was done in Exercise 3.

Q1: At which node would you expect a crack to initiate?

A1: ______________________________________
____
____

Go to the P3⁄PATRAN main menu

Applications Open the Applications pull-down menu.

P3/FATIGUE Open the P3/FATIGUE form.

Now the P3/FATIGUE main menu is displayed. The options are in the correct order for setting up and submitting the fatigue analysis job.

Q2: What type of analysis is this?

A2: ______________________________________
____
____

Step 2 Setting up the P3⁄FATIGUE job

Crack Init. The *Analysis* type that we are performing is Material Nomial Stress Life

Nodal Use stress *Results* at nodes.

Stress Use stress *Tensor* of the results.

MPa Stress *Units* as prescribed from the P3⁄FEA job are MPa

key_en Enter the *jobname*

Use the Title to give a description of the job. (S-N analysis of bracket specimen)

Solution Params… Click on the Solution Params button in the P3/FATIGUE form.

Strain-Life Set the *Analysis Method* option menu to Strain-Life.

50 Set the *Design Criterion (%)* to 50.

OK Click on the OK button to close the form.

Now that you have entered generic strain life information, you will enter the PFMAT module to examine the fatigue properties of MANTEN and RQC100 material sets.

Step 3 Materials Data

Material Info… Click on the Material Info button in the P3⁄FATIGUE form>**1**Choose the **1.Materials** Option.

Database Manager Click on the Database Manager button in the Materials Information form.

This option invokes the program PFMAT, P3⁄FATIGUE's materials manager. The main menu allows us to list, search, create, edit and graphically display existing data sets as well as helping to classify welded details.

In this case the data sets for MANTEN and RQC100 are already stored in the standard database, which is held in a read-only location for security reasons. However, since you do not wish to edit the data, you can examine and use the version stored in the secure database.

Use the **Load** option to load the data sets. Use **Tabulate** to look at the parameters in detail.

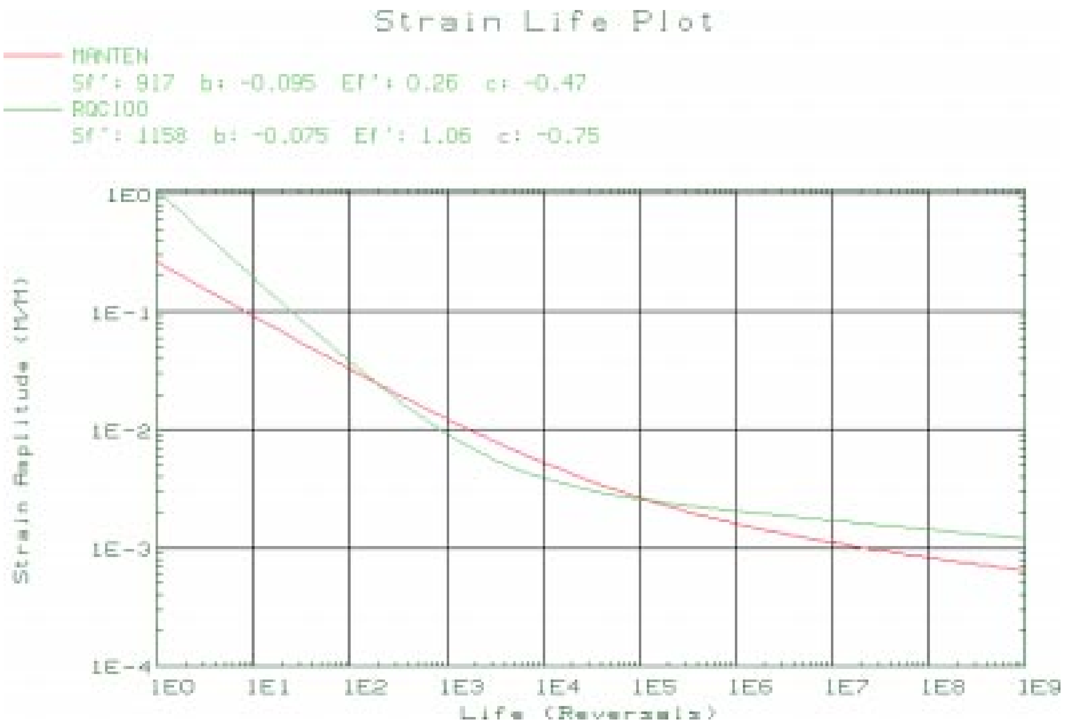
Load...	Select the **Load** option.
data set **1**	Load the first material.
Type Name	Use the **Type Name** option.
MANTEN	Type the name of the first material.
Load...	Select the **Load** option.
data set **2**	Load the second material.
Type Name	Use the **Type Name** option.
RQC100	Type the name of the second material.
Tabulate...	Pick the **Tabulate** option and look at the **Data values** over the next screen pages.

Q3: Which material do you think will give the longest life?

A3: ______________________________________
____
____

Now you can look at the data graphically. Choose the **Graphical display** option from the main menu. Look at the **Strain life plot** first.

Graphical display...	Pick the **Graphical display** option.
Strain life plot	Graph the strain-life curve.



Q4: What can you deduce from these curves?

A4: ______________________________________
____
____

Exit from this curve. Look at the STW curve, which includes mean stress effects.

Exit Click on the **Exit** option on the right vertical menu to return to the non-graphical screen.

st**W** life plot Graph the STW-life curve.

Q5: What effect does mean stress have on the comparison between the two materials?

A5: ____

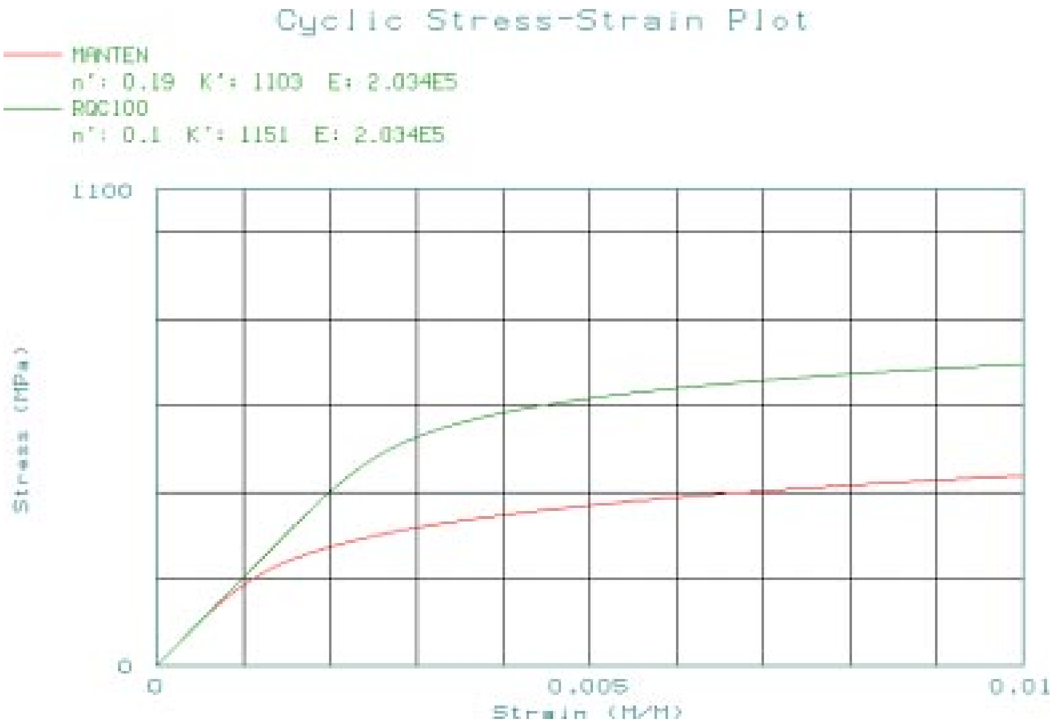
____

____

Why is this? Look at the cyclic stress strain behavior.

Exit Click on the **Exit** option on the right vertical menu to return to the non-graphical screen.

Cyclic stress-strain plotGraph the cyclic stress-strain curve.



Q6: What do you deduce from this plot?

A6:

____

____

____

Now exit from PFMAT.

1 Set the *Number of Materials* to one.

MANTEN Click on the *Material* table cell in the Selected Materials Information spread sheet. In the Select a Material: listbox, click on the MANTEN material. You will examine RQC100 in the second run.

Polished Select Polished from the *Surface Finish* option menu.

No Treatment Select No Treatment from the *Surface Treatment* option menu.

default_group	In the *Select a Group* listbox, select the only group available; default_group.
OK	Click on the OK button to close the form.

Step 4 Time History Information

The time history to use is a scaled version of the Society of Automotive Engineers, SAE, transmission time history, called SAETRN.

When you select Loading Info's Database Manager, a program called PTIME is invoked. PTIME has a central database which holds copies of the SAE time histories normalized to +/-999. The time history you will be using in this exercise is stored in PTIME's Central database. You will first copy this database and scale it appropriately for this application. To do that, choose the **Copy from central** option to make a local copy of **SAETRN** from the central database. Next you must **Modify** the time history through a **Polynomial transformation** (in this case simply linear). This is identical to that done in Exercise 3 but is quickly repeated here.

The linear scaling factor to use is 15.88, to convert the maximum value to be equivalent to 15.86 x 10^3N. The following PTIME commands would generate the time history:

Loading Info	Open the Loading Information form.
Static	The *Results Type* is static
P3/FEA	The *Results From* is P3/FEA
N/A	*Shell Surface* is not applicable.
key	*Select the P3/FEA job* with the stress values for the fatigue analysis.
Database Manager	This will spawn the PTIME module.
Copy from central	Copy from central database option. Press **F**3.
Tag/untag	Tags the SAETRN by placing a astrix * next to it.
a**C**cept	Accept all time histories that are tagged.
Modify a history	Choose the **Modify a time history** option.
Polynomial trans	Chose the **Polynomial transform** option.

F1	Accept the next screen. Make sure that SAETRN is the indicated time history. Answer **Y**es to overwrite.

Press the arrow key to position the cursor to pick the second field and type **15.87** (Case of simply linear). You can use the **Tab** key to clear the field.

Press **F1** key to accept the screen. The transformation will be performed and then you will be asked if you wish to edit the details of the time history. Answer **Y**es. Fill out the next screen with the following:

Description 1	Leave the same.
Description 2	Change to be more meaningful since we have scaled it now.
Load type	Use the **space bar** to change this to **Force**.
Units	Use the **space bar** to change this to **Newtons**.
No. of equiv units	Leave this the same.
Fatigue equiv units	Leave this the same.

Press **F1** key to accept from screen.

Return to the PTIME menus, then exit back to the Loading Information form.

1	Set the *Number of Static Load Cases* to one.
1	Load Case ID number in P3/FEA job.
SAETRN	Enter the modified version of the SAETRN time history with the type of Force and Units of Newtons.
30000	In the *Load Magnitude* databox, enter the value of one.
OK	Click on the OK button to close the form.

Now the job setup is complete. Submit the job as follows:

Click on the Job Control button in the P3/FATIGUE form. Submit a full analysis of the job. Enter the following keystrokes.

Step 5 Submitting the P3⁄FATIGUE job

Job Control Click on the Job Control button in the P3⁄FATIGUE form.

Full Analysis The *Action* option menu should be set to Full Analysis.

Apply Begin the analysis submit.

The job is now submitted and the job progress can be monitored using **Monitor Job** option on the Job Control form. Note that various processes will be executed and the whole job is not complete until the **Fatigue analysis completed successfully** message appears.

Step 6 Reviewing Results

When the job is successfully completed, use the **Results** button on the main P3⁄FATIGUE form to locate the node where the shortest life occurs and the life value.

Results… Open the Results menu.

List Results Change the *Action* option menu to List Results.

Apply Click on the Apply button. This will spawn a separate P3/FATIGUE module called PFPOST.

At this point you are in a separate P3/FATIGUE module called PFPOST from which you can readily determine the location with the most damage. Use the following keystrokes in PFPOST or use the mouse if you have this option.

F1 Press **F1** or click on **OK** to select the current jobname.

Most damgd nodes To list the ten most damaged nodes.

Q7: Which node has the shortest life?

A7:

____

____

____

Q8: What is the shortest life?

A8: ____________________
____
____

Now return to the P3/FATIGUE results menu by pressing **any key** and use the **eXit** fatigue option from PFPOST.

To contour calculated damage estimates, you must import the fatigue results into P3/PATRAN.

Read Results	Change the *Action* option menu to Read Results.
Apply	Click on the Apply button. This will read in the results file from P3/FATIGUE analysis.
Results	In the *Main Window*, click on the Results toggle.
Damage	On the Results Display form, in the *Select Result* listbox, select Damage.
Plot	Use the default settings for the fringe plot. Click on the Plot button.

Q9: Is the result as we expected?

A9: ____________________
____
____

Q10: What do the damage numbers mean?

A10: ____________________
____
____

Try plotting some of the other results available. When you are finished, close the Results Display form by clicking on the Results toggle in the Main Window. The P3/FATIGUE form should still be open.

Step 7 Design Optimization

Now you can achieve the rest of the objectives using results option **Optimize**.

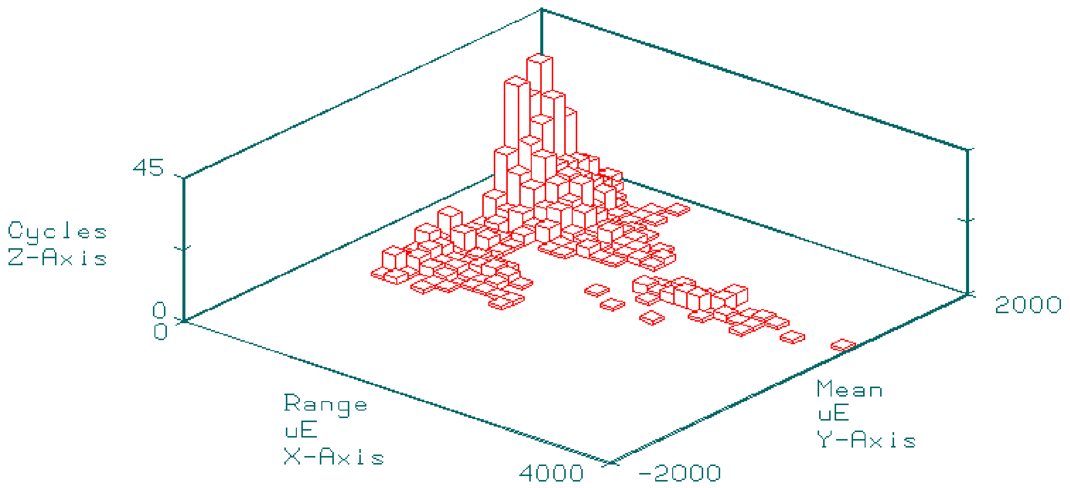
Results	On the P3/FATIGUE main form, click on the Results button.
Optimize	Set the *Action* option menu to Optimize.
Node 13	Select the Worst Case Node to optimize.
Apply	Click on the Apply button.
F1	Accept the screen and leave the Design Life field blank. Note that the exact same results are had.

Display the results histograms.

results **D**isplay...	Select the **results Display** option.
plot **C**ycles histogram	Invoke the histogram graphical display.
Plot type	Change to the Plot type menu.
Damage	Toggle to a damage histogram plot by selecting **Damage** on the right vertical menu of the graphical screen that appears.

Cycles Toggle back to cycles histogram plot.

CYCLE HISTOGRAM DISTRIBUTION FOR : KEY_EN13.CYH
Maximum height : 45 Z Units :



Q11: What do the distributions of cycles and damage show?

A11: ____

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When you are finished looking at the histogram plots, return to the non-graphical screen by picking the **Main** and **Exit** options on the right vertical menu of the graphical screen. At the main menu of DESOPT, select **Sensitivity analysis** to change the mean stress correction methods to all.

Sensitivity analyss	Choose the **Sensitivity analysis** option which will give a submenu.
Mean strss corr(all)	A recalculation will be done using all mean stress correction methods.
Recalculate	Performs a recalculation.

Q12: Which method gives the shortest life?

A12: ____
____
____

Q13: If SAETRN had a negative mean, what change would the various correction methods give in life estimates?

A13: ____
____
____

Q14: How do these lives compare with the S-N approach?

A14: ____
____
____

Press **return** and change the a set to RQC100. Repeat the nodal analysis.

Material optimization...Choose the **Material optimization** option which will give a submenu.

Material change	Select the **Material change** option. A field will be presented where you can enter a new material name.
RQC100	Type in the new material name. You can clear the existing name by using the **Tab** key.
Recalculate	Performs a recalculation.

Q15: What is the effect on life?

A15: ____
____
____

Now change back to MANTEN. Look at the effect of surface finish by analyzing the node with GOOD, AVERAGE and POOR MACHINED surfaces. *(Hint: You can use the* **ALL** *option.)*

Original paramtrs	This resets everything to the original defaults when you first entered DESOPT.
Sensitivity analyss	Choose the **Sensitivity analysis** option which will give a submenu.
surface **F**inishs(all)	A recalculation will be done using all surface finishes. Note that above the menu picks it indicates that this option has been turned on.
Recalculate	Performs a recalculation.

Q16: Is the difference in life significant?

A16:

____

____

____

When you are finished with the exercise exit from DESOPT and quit from PATRAN.

e**X**it	Exits from DESOPT.
File/Quit	Quits from PATRAN.

List the files in your directory.

Exercise 5 Solutions

A1: In this case, we have a single load case, single material model with no localized surface effects, so we can predict that the crack will initiate at the node with maximum stress, in this case node 13

A2: Crack initiation, option 2.

A3: Based on a comparison of Sf’ and K’, RQC100 looks better.

A4: RQC100 is better in the range 1 to 100 cycles and again from 1E5 to 1E9. In the center section MANTEN is better.

A5: It makes RQC100 better at all life values.

A6: The strain response of RQC100 at a given stress is less than MANTEN. This means that RQC100 is a stronger material and should be better when elastic effects dominate the fatigue life, i.e. at long lives.

A7: Node 13

A8: The shortest life is approx. 9000 repeats of the history.

A9: Yes, the point of highest stress is the crack initiation site. Notice that the damage values are more localized than they were for the S-N approach. This is because this method models local behavior more accurately. You may wish to zoom in on this area.

A10: The damage value is the reciprocal of the repeats to failure.

A11: This is the rainflow matrix extracted from the time history. The first plot shows the number of cycles extracted plotted against their stress or strain range and mean depending on whether you chose to use a stress or strain tensor respectively. The second plot or damage histogram shows the actual damage caused by each cycle. Obviously there are many cycles at lower stress ranges that cause no or little damage, however, the higher range cycles have the damage spread fairly evenly. This means we cannot point to a single event as the cause of the failure.

A12: Smith-Topper-Watson (This is the most conservative for this material and load history combination.) (Check this by adjusting the mean of the load history and re-submit the job.)

A13: The strain life method would be un-changed. The two correction methods would predict longer lives.

A14: The lives are within a factor of 2, particularly if we apply a design criterion of 96%, we would usually expect the S-N approach to be longer than initiation because some crack growth is included in the S-N prediction.

A15: RQC100 is significantly better using all mean stress methods.

A16: The life estimations are around a factor of 2 worse. This means that the effect is worth consideration, since it is unlikely that a real component will be polished.