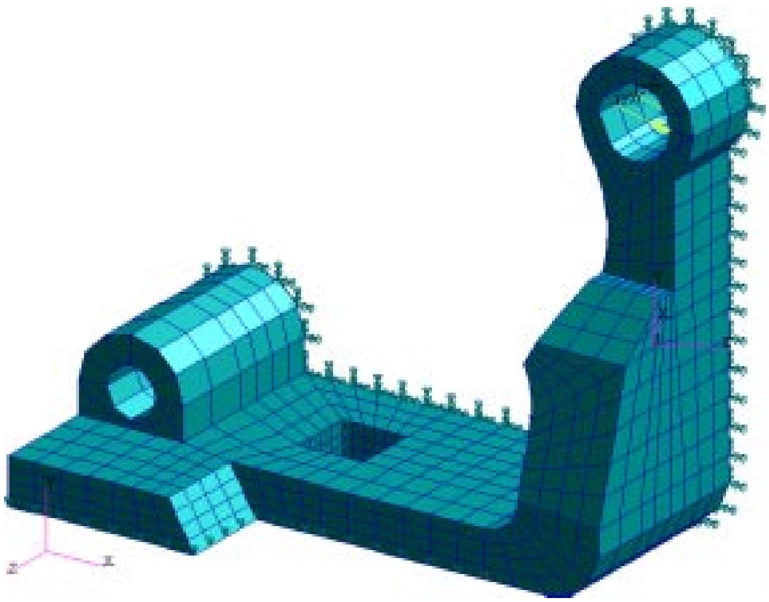
LESSON 7

Fatigue Analysis of a Hinge



Objectives:

- To find a combination of material, surface finish and surface treatment which will meet the design life. This will be achieved in a number of steps.
- To assess the life to initiation of a crack for the hinge under the prescribed loading history.
- To learn how to go about finding fatigue solutions based on the evidence buried in the result of the first analysis.

Problem Description:

Step 1 Problem Description

This exercise is based around a crack initiation design problem associated with a hinge used in a piece of machinery. The design life for the hinge is 15,000 operations.

A geometry model of the hinge has already been created in PATRAN 3 and is stored under the neutral filename **hinge.out**. The load applied to hinge acts through the top hinge point and an FE analysis has been performed using P3/FEA to simulate the application of a maximum total load of 9.067 kN. The results of this analysis are stored under the filename **hinge.res**. (Again you must use RESTXT to convert this file from **hinge.txt**.) (Also make sure you are in the **ex07** directory of your PAT318 account.)

The initial manufacturing process chosen for the hinge is forging, with the bores for the pin being machined to size after forging. The forgers have suggested that they would use a low carbon steel close in specification to SAE1018. Since a forging is like a hot rolling process as far as fatigue properties are concerned, you should use the material data set SAE1018_106_HR for your first analysis.

The loading time history is based on the history SAEBRAKT which is stored in the central database. You should copy this history and then carry out the modification given in the equation below to re-scale the history for use in this analysis:

((SAEBRAKT * (-1.0)) + 500) * 9.067 / 1499

The history is equivalent to 200 OPERATIONS and the load type is FORCE with units of kilonewtons (kN).

Exercise Procedure

Step 2 Setting up the P/FATIGUE job

By now you should be becoming familiar with PATRAN 3 and P3/FATIGUE. Remember to first review the stress results, boundary and loading conditions. Also check to see if there are hyperpatches available for use in assignment of material properties in the fatigue analysis. If not, look at node numbers in the region you choose to analyze.

Crack Init.	The *Analysis* type that we are performing is Strain Life or crack initiation analysis
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
Hinge	Enter the *jobname*
	Use the Title to give a description of the job. (E-N analysis of the plate assembly)

The next step is to define the job parameters. Use the stresses from the FE analysis and you could choose either the Max. Abs. Principal stress or the Signed Von Mises stress, as the principal stress field is highly aligned to the global X-direction. Remember the sum of the point load applied in the FEA is 9.067 kN. Stresses are in MPa.

Solution Params…	Click on the Solution Params button in the P3⁄FATIGUE form.
S-T-W	Set the *Mean Stress Correction* option menu to Smith_Topper_Watson.
50	Set the *Design Criterion (%)* to 50. Click on the OK button to close the form.

First review the materials data by entering PFMAT and tabulating the datavalues after loading in SAE1018_106_HR.

Q1: Write down the values of the crack initiation fatigue parameters for SAE1018_106_HR - you will need them later.

A1: ____________________________________

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Q2: If there are 100 cycles in the load history, how many cycles are there in 15,000 operations and what strain level would give a life of this many cycles?

A2:

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Loading Info…	Open the Loading Information form.
Static	The results are static
P3/FEA	The results code is P3⁄FEA
N/A	Shell Surface is not applicable.
hinge	Select the P3/FEA job with the stress values for the fatigue analysis.
Database Manager	This will spawn the PTIME module.

Having reviewed the materials data, now create the time history as described above. Check the history using the graph option. The maximum value after scaling should be 9.067 kN.

Hint: Use the **Polynomial transform** option of PTIME under the **Modify a time history** submenu after copying SAEBRAKT from the central database. When preparing the time history, do the x - 1.0 and +500 in one operation (after this operation Ymax = 1499, Y min = 500) followed by the multiplication by 6.049E-3 to give a Ymax = 9.067kN.

Q3: What is the mean value of the load history and which mean stress correction method do you think you should use to be conservative?

A3:

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1	Set the Number of Static Load Cases to one.
1	Load case number in P3/FEA job.

SAEBRAKT	Enter the modified version of the SAEBRAKT time history with the type of Force and Units of Newtons.
9.067	In the Load Magnitude databox, enter the value of one.
OK	Click on the OK button to close the form.

Submit the job and monitor it until the message **Fatigue analysis completed successfully** appears.

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	Submit the analysis job.

The job is now submitted and the job progress can be monitored using the **Monitor Job** option.

Review the results using the results listing option.

Step 3 Reviewing Results

Q4: What is the shortest life reported and with which node is it associated? Has the design life been met?

A4:

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Providing you have run the job with the parameters as expected, you should find that the design life has not been met by about a factor of over 30%.

Q5: There are a number of possible solutions for the fatigue problem - what are they?

A5:

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Step 4 Design Optimization

You will now assess the possible solutions for this hinge fatigue problem. Some will be viable and other may not. You should consider at least the following solutions.

Q6: What alternative surface finishes extend the life beyond the design life and what lives do they give? Are these realistic solutions based on the fact that the lives reported are mean (50% confidence) lives?

A6:

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Q7: Do any of the surface treatments help enough to justify their additional expense?

A7:

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Q8: Can the life be improved easily by reducing the stresses around the hinge bend? What reduction factor is needed to achieve twice the design life (incorporating a factor of safety of 2)? Is it practical to increase the material thickness in this region?

A8:

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Q9: A lap defect from the forging operation introduces an additional stress concentration factor of between 1.2 and 1.8. How sensitive is the fatigue life to such a defect?

A9:

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Although these options can provide a solution, it could be that a change in material will solve all the potential fatigue problems by giving a much better life. Your job is to find a suitable material using the search facilities in the materials database. First, however, you will need to decide if the fatigue problem is a high or low cycle one. To do this you will need to look at the cycles and damage distributions.

Hint: When plotting a cycle histogram under the **display Results** option from DESOPT's main menu, using the **View Left** option you can see a 2D view of all the cycles sorted into ascending ranges, switching to the damage histogram will indicate which cycles cause the most damage. From this you can estimate the number of cycles causing most of the damage. Then go to the strain-life curve and look at the cross-over point of the elastic and plastic lines. Or you can simply look at the bottom of the results display page after doing a recalculation using DESOPT and it will tell you how many cycles fell in the low/transition/high regions.

Searching for materials is done in PFMAT from the main menu under the **Search and list** option.

Hint: When the **Selective Materials Listing** page comes up in PFMAT after invoking **Search and list** option, fill in the **Name** field with **SAE**, the **Strain Data** field with **Yes**, the **Sf**', **b**, and **Ef**' fields with numbers greater than (>) those answered in question 10 below. Use the first two materials that appear in the list generated.

Q10: Is the fatigue a HIGH, LOW, or TRANSITION cycle problem? What parameters do you need to improve to get a better HIGH cycle fatigue life. What about an improvement in the LOW cycle properties - which parameters control this?

A10:

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Q11: List the two materials you think might give better lives. Remember, if you select a QT data set that implies a need to quench and temper the hinge after forging; this will add to the manufacturing costs.

A11: Material 1: Life:
Material 2: Life:

Now re-run DESOPT and try the material you have selected. Fill in the lives in the space above next to the material name.

Q12: What is your final recommendation for the choice of material, manufacturing process and surface treatment for the hinge? Why have you chosen this combination?

A12:

Exercise 7 Solutions

A1: Sf':782, b: -0.11, c: -0.41, Ef': 0.19, n': 0.27, K': 1259, NC: 2E8, YS: 250, UTS: 354, E: 2.07E5.

A2: 7,500 cycles which is15,000 reversals and strain level of 4.82E-3.

A3: Mean: 3.339, standard deviation: 1.35, RMS: 3.602. Smith-Topper-Watson method is the most conservative one.

A4: Node 951 with shortest life of approx. 8000 operations if you used Max. Abs. Principal stress(approx.10,000 operations, signed Von Mises stress). The design life has not been met.

A5: Possible solutions are:

- Different material
- Different surface treatment
- Different surface finish
- Thickening the region of hinge bend

A6: Alternative surface finishes for Max. Abs. Principal stress (signed Von Mises):

Polish:approx. 23,000(32,000) operations
Ground:approx. 18,500(25,500) operations
Good:approx. 15,500(21,000) operations
Average:approx. 13,000(17,500) operations
Poor:approx. 11,500(15,500) operations
Hot Rolled:approx. 12,500(17,000) operations
Cast:approx. 7,500(10,000) operations

Therefore, it is not a realistic solution based on confidence level of 50% unless you were to polish the part which is probably unfeasible and costly.

A7: Surface treatment of forged finish for Max. Abs. Principal stress (signed Von Mises):

Nitrided:approx. 39,599(5.64E4) operations
Shot peened:approx. 39,599(5.64E4) opers
Cold Rolled:approx. 8,000(10,500) operations

There is no simple YES or NO answer. Shot peened surface treatment is less expensive than Nitrided. However, in reverse loading, shot peened loses its effect. Therefore, you may have to select Nitrided surface treatment.

A8: Need to reduce load factor by (1-.73)*100 = 27% to incorporate a safety factor of 2. (Design life = 30,000 Operations.)

A9: It is sensitive. For 1.2 stress concentration factor, life reduces to approx. 3,500 operations. For 1.8 stress concentration factor: life reduces to approx. 700 operations.

A10: The parameters you need to improve are the material properties. To find a better material check for low/high cycle fatigue. If low cycle, look at current b, Sf, and K', the strength parameters. Then search on material properties, e.g., Sf > 782, b > -0.11 and K' > 1259. If high cycle look at the ductility parameters. It is a 94% low cycle fatigue problem, 4% transition, and 1% high cycle.

A11: SAE1045_390_QT: life of approx. 175,000 operations, SAE1045_450_QT: life of approx. 2,210,000 operations

A12: The recommended material is SAE1045_390_QT with no surface treatment gives the life of approx. 175,000 operations with a safety factor of over 11.5.