

***Applied Reliability Engineering
for Operating Plant Reliability Improvement***

*Module 4, Activity 1: Bending Stress in Steel
Parts – Reliability Analysis.*



Applied Reliability Engineering for Operating Plant Reliability Improvement

Module 4, Activity 1: Bending Stress in Steel Parts – Reliability Analysis. [Mayez Chikhany]

Introduction

As part of Module 4 of the 'Applied Reliability Engineering for Operating Plant Reliability Improvement' training course provided by Lifetime-Reliability Solutions, trainees are introduced to the key concepts of reliability analysis.

Activity 1 of this module links back to one of the activities of Module 1 "Science of Failure", with a view at conducting a reliability analysis on the observed behaviours.

To recap from Activity 1 of Module 1, the key objectives were:

- Studying the failure response of a steel paper clip to an induced cyclic overstress.
- Developing & simulating a procedure for making paper clip bending a more certain outcome.
- Optimising the reliability of the process by fine tuning the developed procedure.

Methodology & Simulation Results

Paper clip failure was simulated over three stages:

- At the first stage, paper clip failure was simulated without following a specific procedure.
- A procedure was then developed and simulated with a view at setting clear instructions and quality specifications such that task variation is minimised.
- At the final stage, the developed bending process was improved upon, increasing its reliability by making appropriate changes to the procedure, reducing operating stresses for the clips. The process was then simulated.

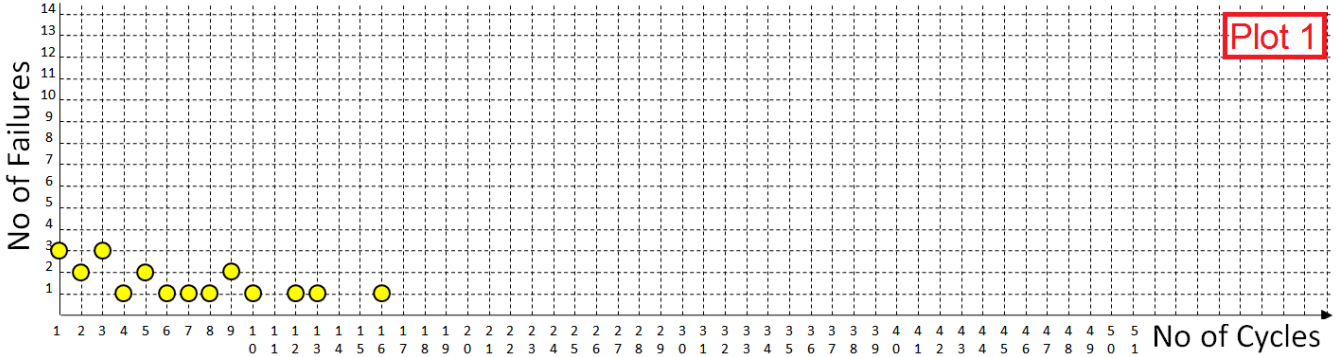
The developed paper clip bending procedures as part of Module 1 are illustrated on Pages 4 & 5. In addition, the results from the three simulations (mentioned above) are shown in Plot 1, Plot 2 and Plot 3 on Page 3.

Reliability Analysis

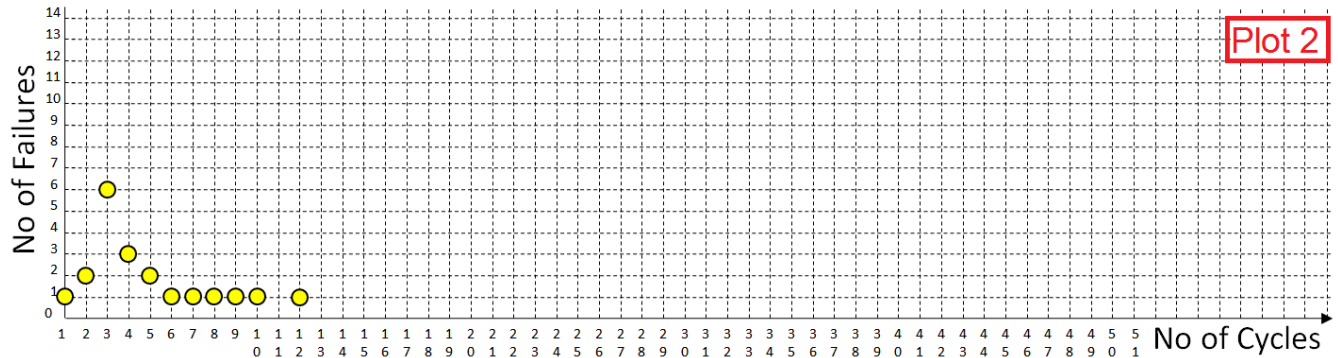
The Reliability analysis carried out as part of this activity, which builds upon the results from the three simulations, can be found on Page 6.

Simulation Results

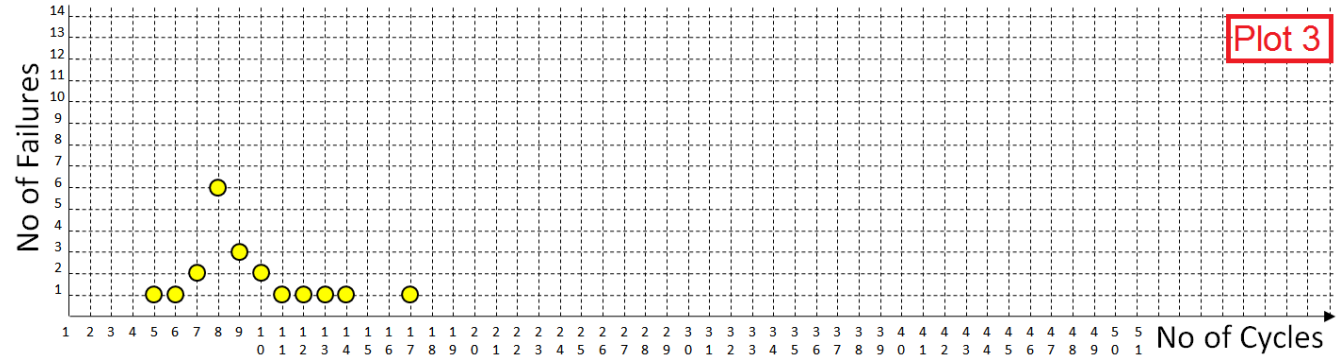
Results from bending paper clips without following a specific procedure:



Results from bending paper clips following Procedure 1:



Results from bending paper clips following Procedure 2:



Procedure 1 - Limiting Task Results Variation:

Stage 1:

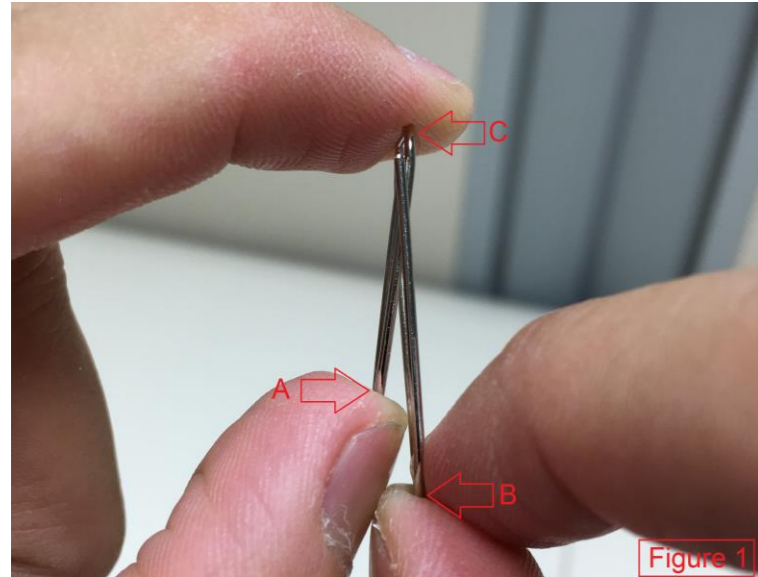


Figure 1

- 1) Hold the clip as shown in Figure 1 above.
- 2) Start opening the clip until it becomes flat at a 180° angle.
Note 1: step to be completed in 5 Seconds.
Note 2: while flattening the clip, keep on supporting section C with the tip of your index finger as shown in Figure 2 below.

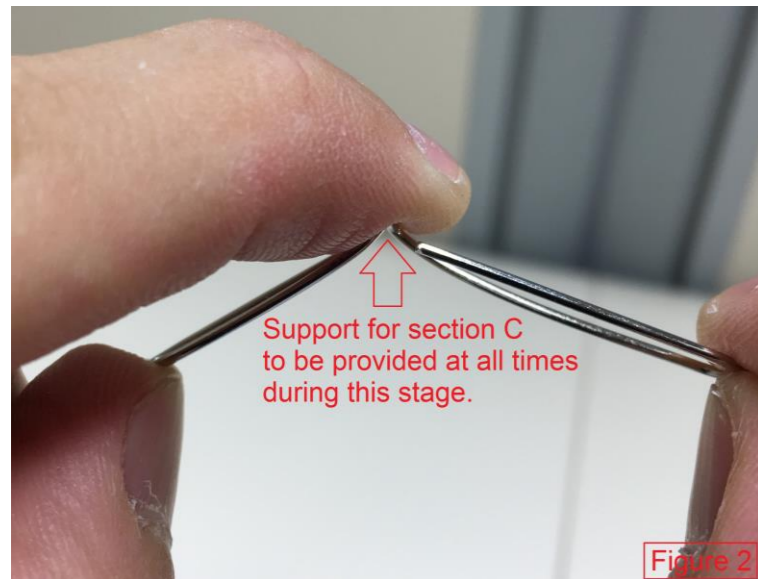


Figure 2

Support for section C to be provided at all times during this stage.

Stage 2:

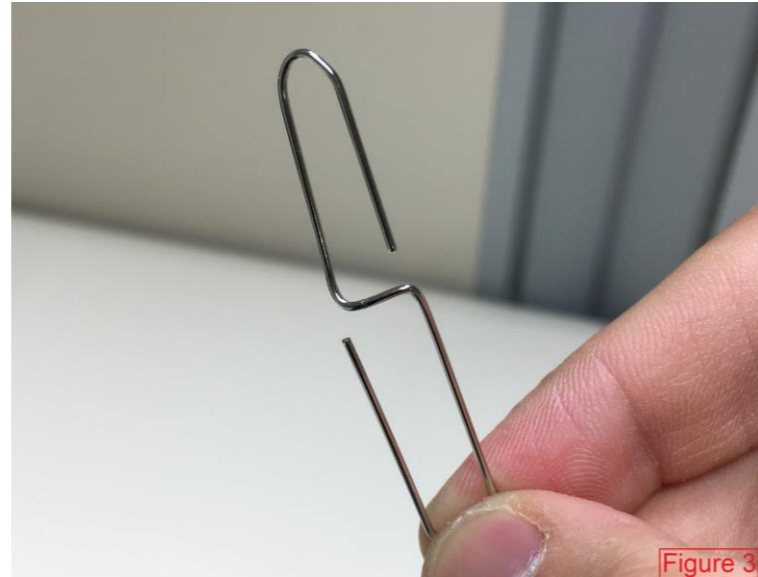


Figure 3

- 3) Once step 2 is completed, the clip should become flat as shown in Figure 3 above.
- 4) Hold both tips of the clip, at A and B with your index and thumb fingers as shown in Figure 4 below. Start closing the clip until A and B are aligned and touching.
Note 3: step to be completed in 2 Seconds.

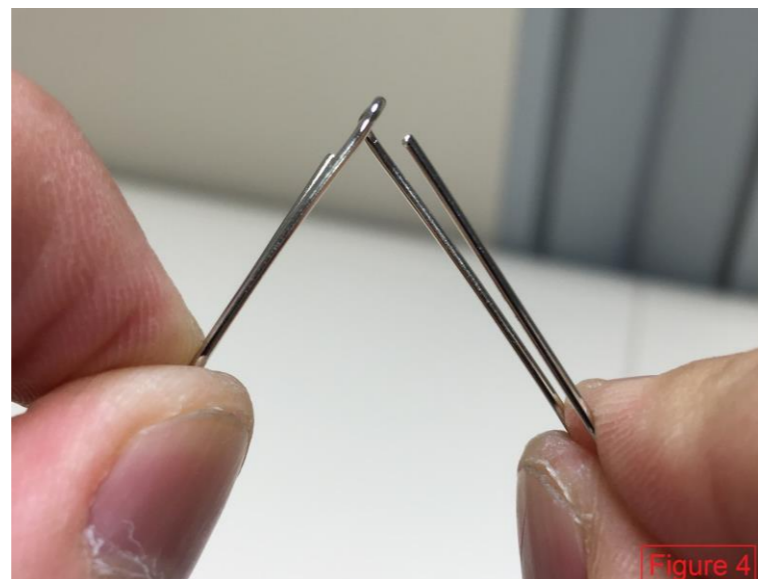


Figure 4

Stage 3:

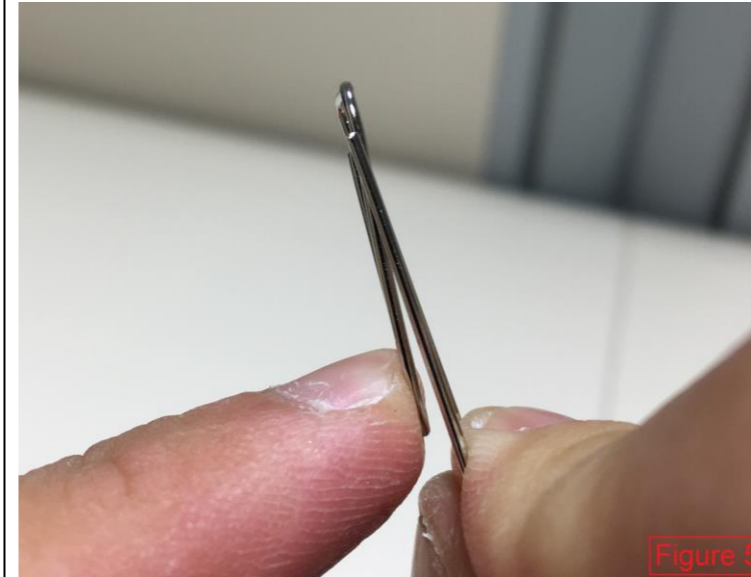


Figure 5

- 5) Once step 4 is completed, the clip should be as shown in Figure 5 above.
- 6) Hold the clip again as instructed in step 1 and start opening back the clip until it becomes flat again at a 180° angle.
Note 4: step to be completed in 2 Seconds.
Note 5: while flattening the clip, keep on supporting section C with the tip of your index finger as shown in Figure 2.

Stage 4:

- 7) Once step 6 is completed, repeat the process starting from step 4. Steps 4 to 6 are to be repeated until the clip breaks. Count the number of cycles until the clip breaks and record the findings.
- 8) Complete steps 1 to 7 for all clips, compile and plot results as shown in Figure 7 below.

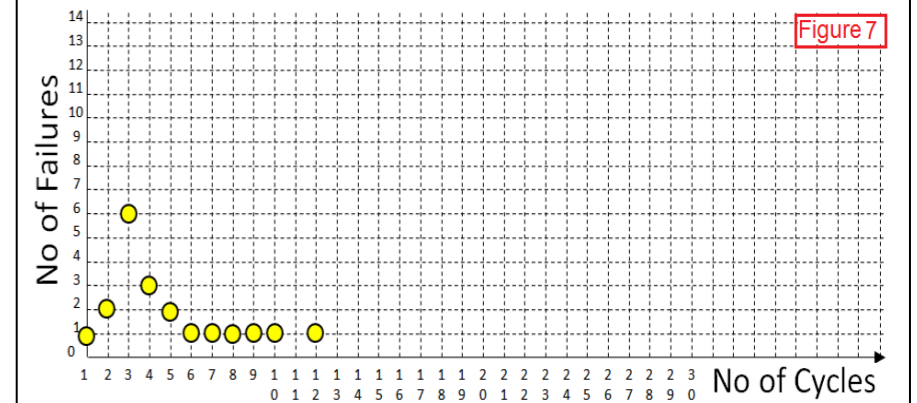


Figure 7

Procedure 2 - Increasing Reliability of Paper Clip Bending Process:

Stage 1:

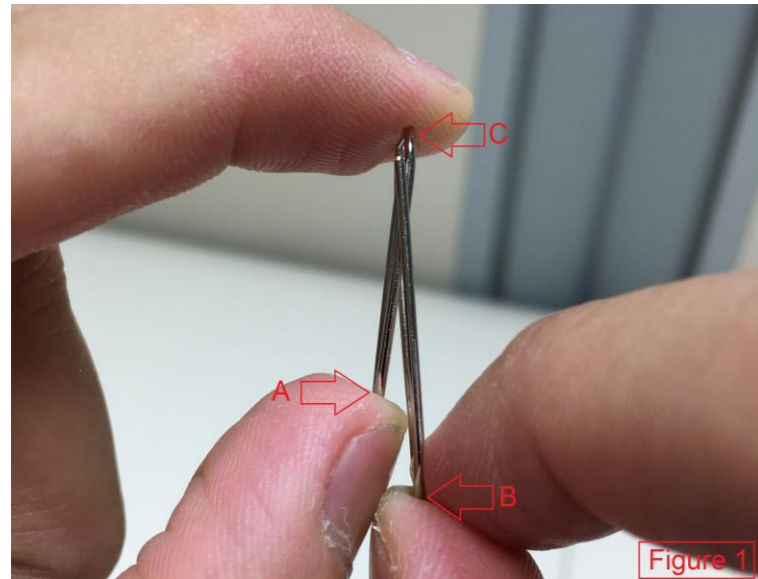


Figure 1

Note 1: cold air is to be continuously blown at section C of the clip during every step of this process.

- 1) Hold the clip as shown in Figure 1 above.
- 2) Start opening the clip in a steady, incremental and intermittent manner, until it becomes flat at a 180° angle.

Note 2: exercise the minimum possible force while carrying out this step, each progression should result in no more than a 20° angle movement.

Note 3: step to be completed in 5 Seconds.

Note 4: while flattening the clip, keep on supporting section C with the tip of your index finger as shown in Figure 2.

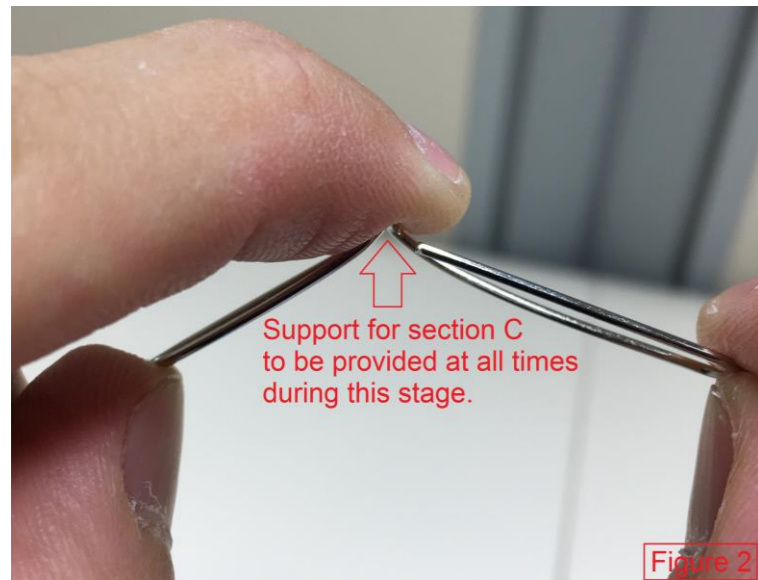


Figure 2

Stage 2:

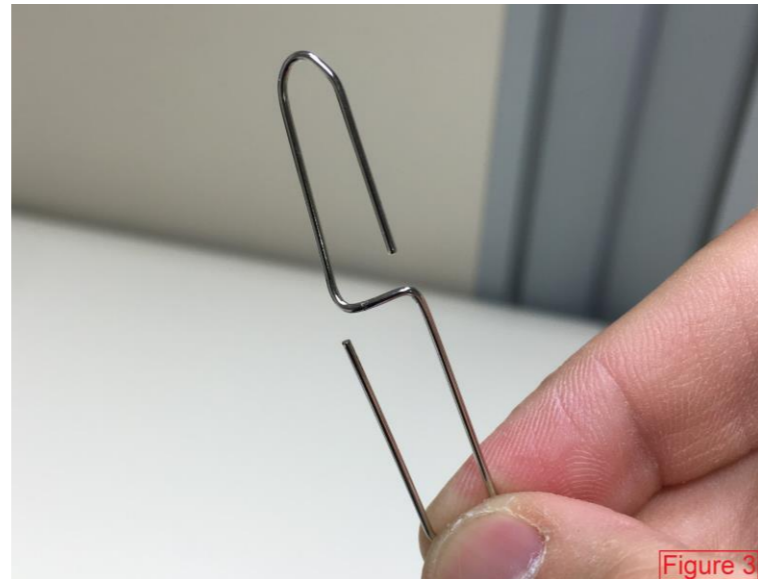


Figure 3

- 3) Once step 2 is completed, the clip should become flat as shown in Figure 3 above.
- 4) Hold the tips of the clip at A and B with your index and thumb fingers as shown in Figure 4 below. Start closing the clip in the same incremental manner as described in step 2 until A and B are aligned and touching.

Note 5: each progression should result in no more than a 20° angle movement.

Note 6: step to be completed in 2 Seconds.

Note 7: while closing the clip, keep on supporting section C with the tip of your index finger.

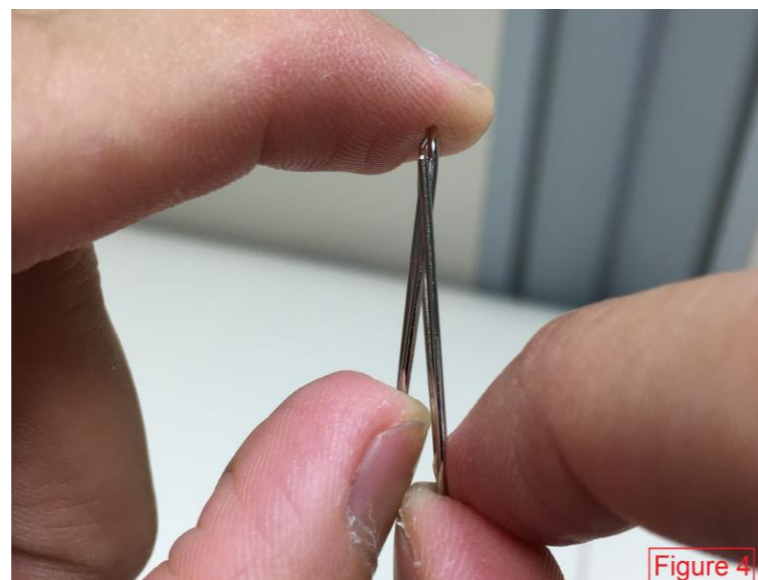


Figure 4

Stage 3:



Figure 5

- 5) Once step 4 is completed, the clip should be as shown in Figure 5 above.
 - 6) Hold the clip again as instructed in step 1 and start opening back the clip in the same incremental manner described in step 2 until it becomes flat again at a 180° angle.
- Note 8: Exercise the minimum possible force while carrying out this step, each progression should result in no more than a 20° angle opening.
- Note 9: step to be completed in 2 Seconds.
- Note 10: while flattening the clip, keep on supporting section C with the tip of your index finger as shown in Figure 2.

Stage 4:

- 7) Once step 6 is completed, repeat the process starting from step 4. Steps 4 to 6 are to be repeated until the clip breaks. Count the number of cycles until the clip breaks and record the findings.
- 8) Complete steps 1 to 7 for all clips, compile and plot results as shown in Figure 7 below.

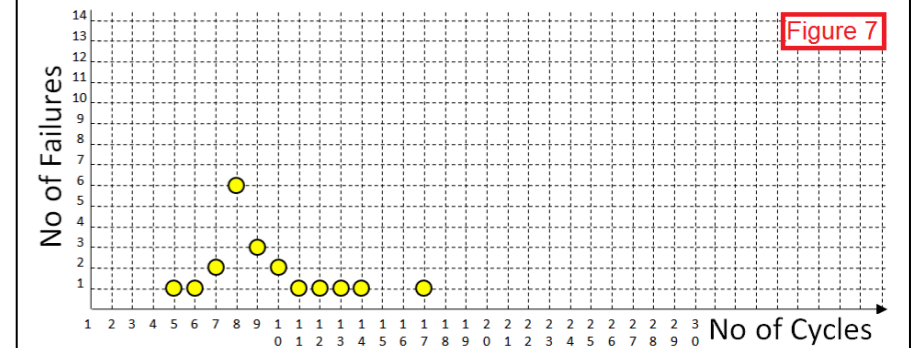


Figure 7

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Module 4, Activity 1: Bending Stress in Steel Parts – Reliability Analysis. [Mayez Chikhany]

Reliability Analysis & Observations

The simulation results from Plot 1 and Plot 3 (Page 3) are studied to assess the impact “Procedure 2 - Increasing Reliability of Paper Clip Bending Process” had on the paper clip bending process.

Results from the simulations are presented in the tables below along with the calculation results for cumulative failures and reliability. Representative graphs are then shown on the page to follow.

Case A - Bending Paper Clips Without Procedure:

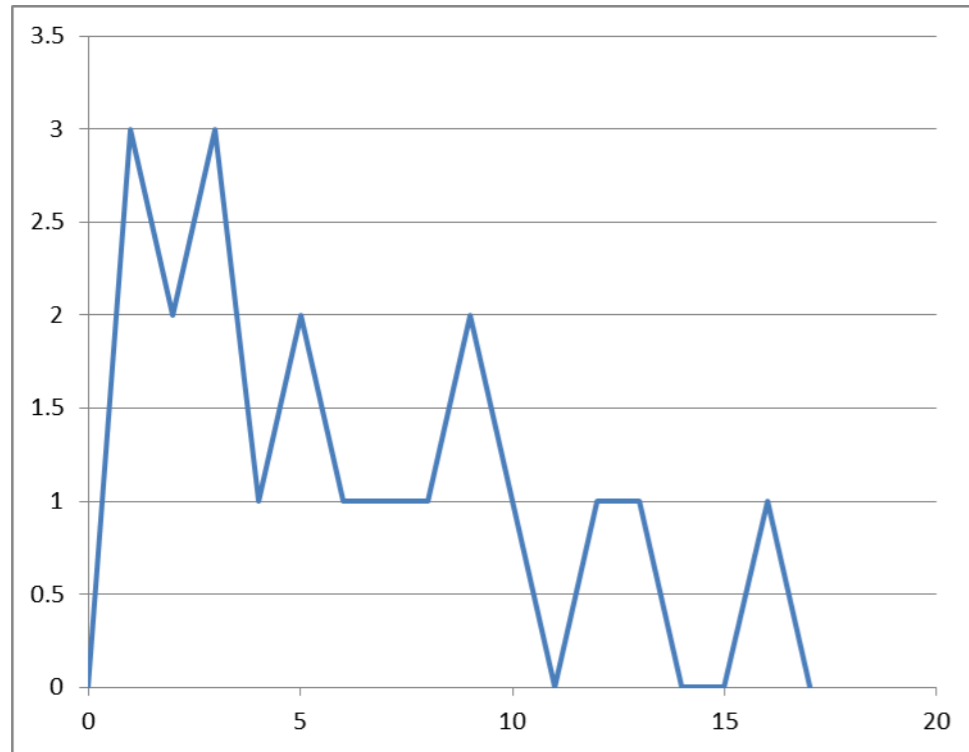
Number of Cycles	Number of Failures	Cumulative Failures	Reliability
0	0	0	1
1	3	3	0.85
2	2	5	0.75
3	3	8	0.6
4	1	9	0.55
5	2	11	0.45
6	1	12	0.4
7	1	13	0.35
8	1	14	0.3
9	2	16	0.2
10	1	17	0.15
11	0	17	0.15
12	1	18	0.1
13	1	19	0.05
14	0	19	0.05
15	0	19	0.05
16	1	20	0
17	0	20	0

Case B - Bending Paper Clips Following Procedure 2:

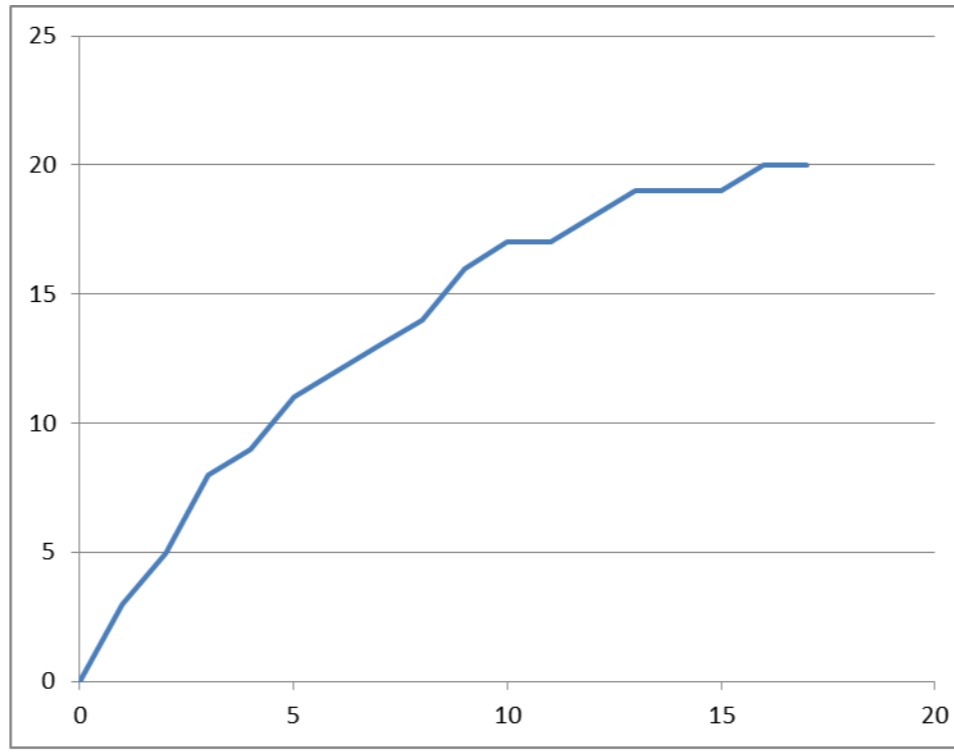
Number of Cycles	Number of Failures	Cumulative Failures	Reliability
0	0	0	1
1	0	0	1
2	0	0	1
3	0	0	1
4	0	0	1
5	1	1	0.95
6	1	2	0.9
7	2	4	0.8
8	6	10	0.5
9	3	13	0.35
10	2	15	0.25
11	1	16	0.2
12	1	17	0.15
13	1	18	0.1
14	1	19	0.05
15	0	19	0.05
16	0	19	0.05
17	1	20	0

The Failure Probability Density Function, Cumulative Failure Distribution Function and Reliability graphs for Case A and Case B are represented below:

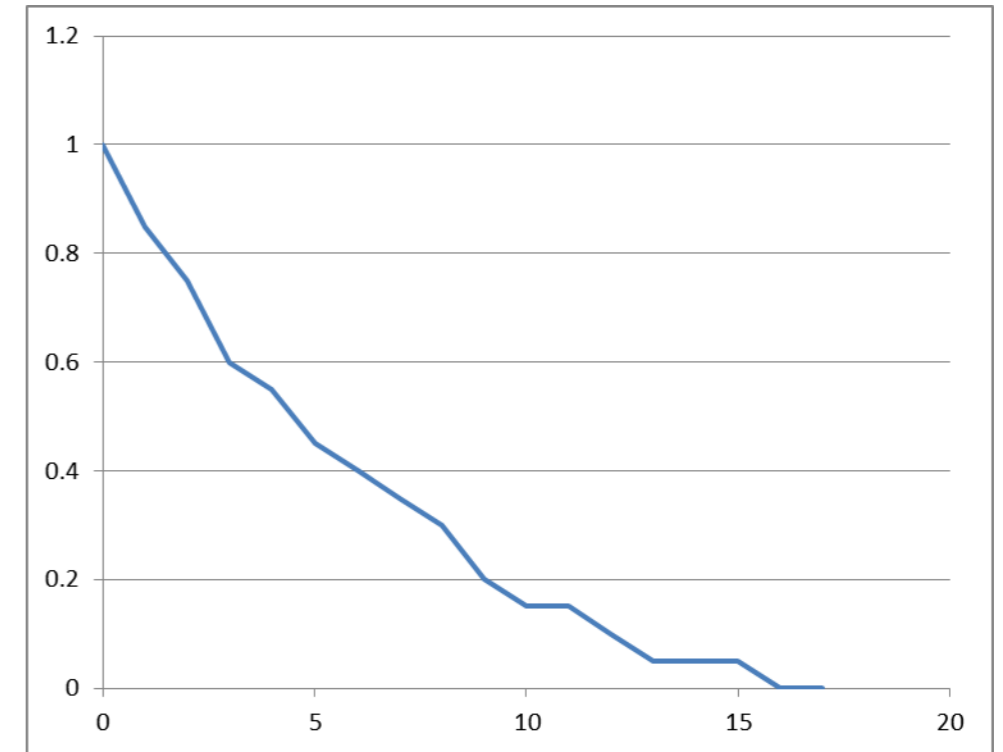
Case A:



Failure Probability Density Function

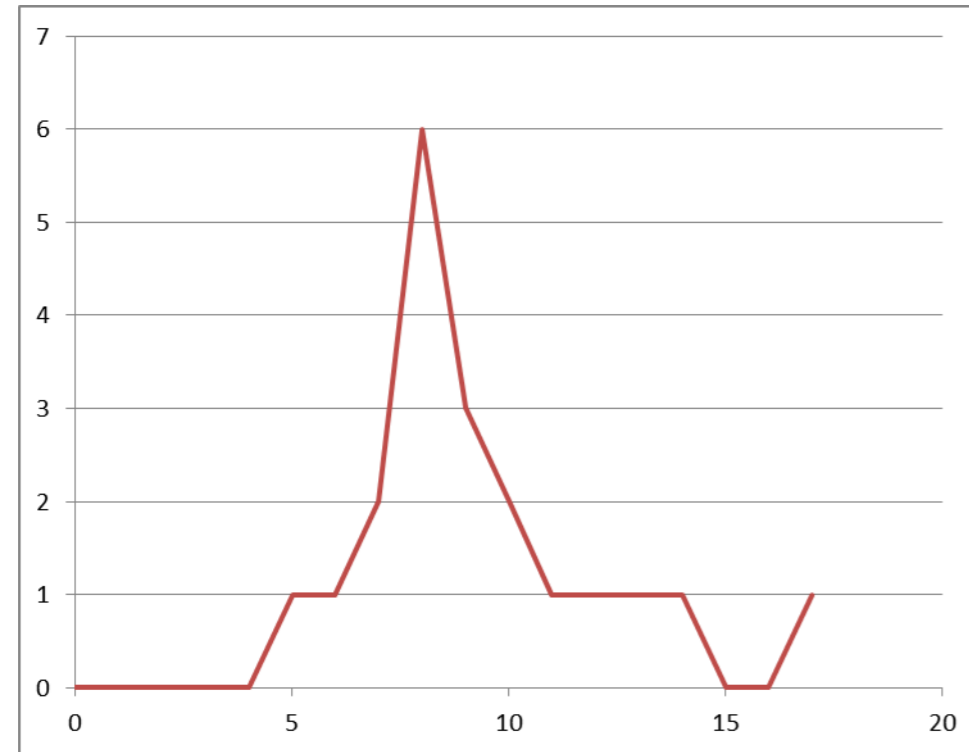


Cumulative Failure Distribution Function

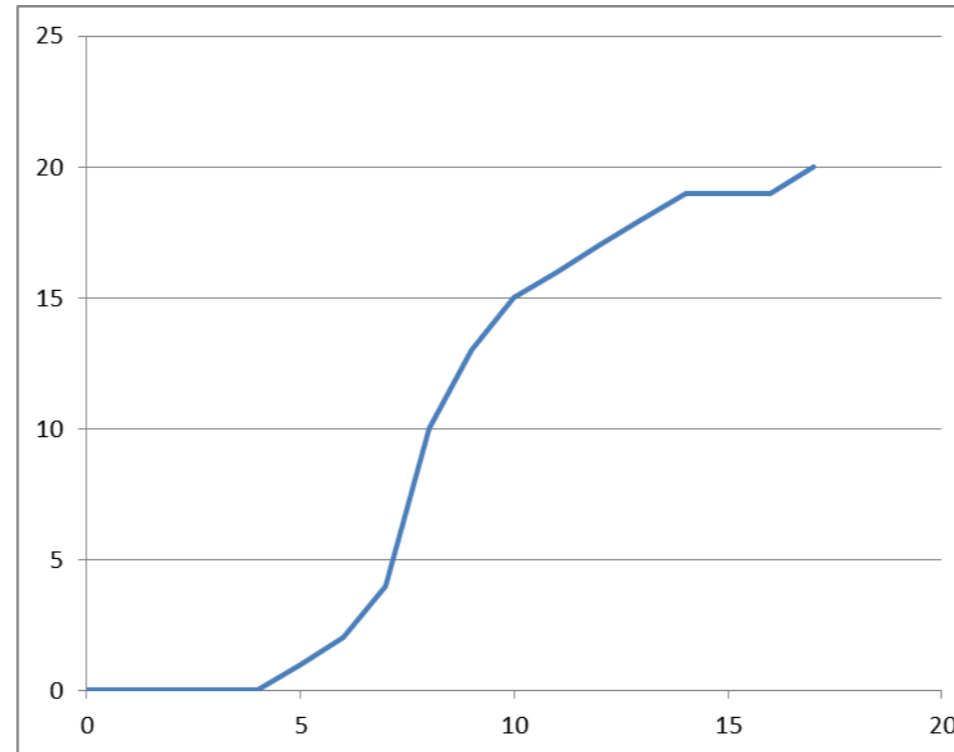


Reliability

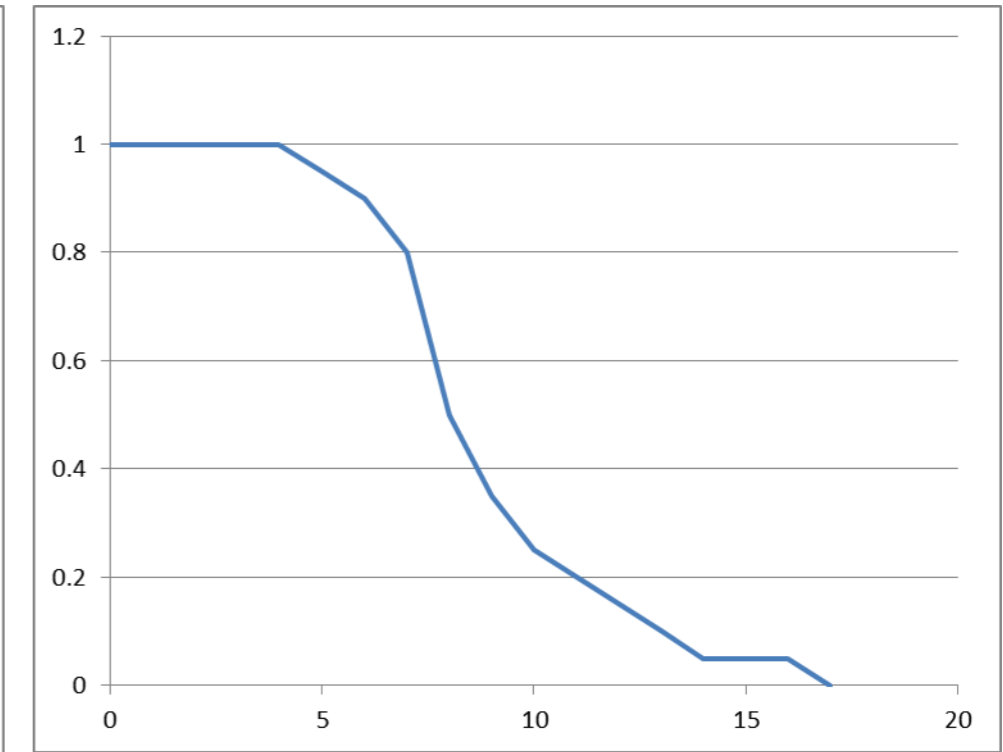
Case B:



Failure Probability Density Function



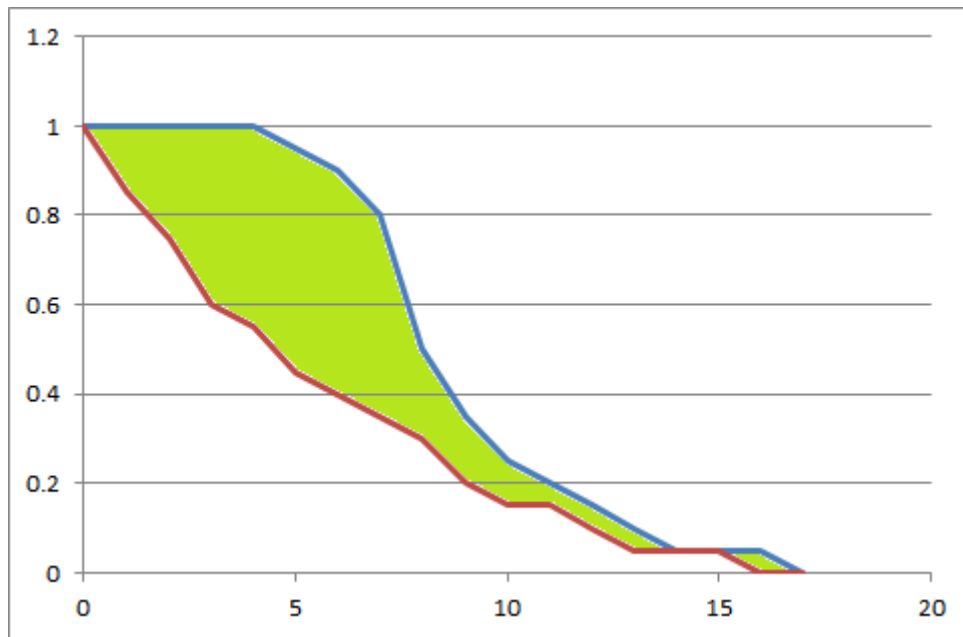
Cumulative Failure Distribution Function



Reliability

Key Observations

- Plotting the reliability graphs over the same axis, as shown in the figure below, illustrates the improvements in reliability (highlighted in green) achieved by following the proposed Procedure 2.



- The improvement in reliability was achieved by:
 - Reducing the operating stress on the clips.
 - Ensuring more favourable operating conditions (cooling down the clip while bending).
 - Eliminating human induced variations in process by providing clear and detailed operating instructions.
- Failure Causes and Mitigation Measures:

Failure Causes	Mitigation Measures
Applied operating stress exceed stress handling capability	Risk reduced through via the applied procedure
Operating temperature exceeds acceptable limits	Risk reduced through via the applied procedure
Sudden application of excessive force on clip	Risk removed through via the applied procedure

- Removing the random aspect of clip failures observed when bending clips without following a specific procedure allows the establishment of an effective operation & maintenance strategy for clips, i.e.:
 - Operating clips within failure free envelope.

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- Improving upon the developed procedure and upon operators' skills with a view at further increasing the failure free operating margins.
- Expecting a considerable increase in failures when approaching the number of cycles with the associated spike on the Failure Probability Density Function.