

TITLE: Designing a Butterfly Valve – Optimisation Techniques Assessment 2

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Introduction

Following the previous work on the butterfly valve. A request was issued to design the lay up of the composite material such that the maximum deformation seen was 0.1mm. This maximum deflection ensures a good seal between the plate and outer housing. The plate needs to use as little material as possible to reduce the cost of manufacture.

Part 1 – FEA and Optimisation

“Discuss FEA optimisation techniques and by referencing appropriate sources, show how they have developed historically and discuss how you think they may develop in the future. Discuss how they improve the design process.”

Finite element analysis or ‘FEA’ is a tool used within computer aided design or computer aided engineering ‘CAD’ ‘CAE’ to predict and analyse how a design may react to conditions that may be applied to it in the real world. FEA allows engineers to quickly understand how model iterations may affect the design. Where, in the past, with ‘old school’ engineering there was a heavy reliance on trial and error, prototyping and previous experience. For new product development the classical approach would be costly. Designs would often not be completely optimised, as more iteration would increase the project timeline and cost.

FEA can be used to understand a number of conditions such as, deflection, stresses, stiffness, ultimate strength, fatigue life, thermal stresses and a number of combined conditions as a verification tool. FEA can be split into three stages, pre-processing, processing and post processing.

Pre processing is the actual creation of the FE model, importing the CAD file, the meshing and setup of the elements (size and type), setting up the constraints, loads, material etc. Pre-processing then, is the actual model set up where you are preparing for the analysis.

Processing is the actual analysis. In our case it is done on genesis. This is where all of the matrix algebra is solved. It is the number crunching portion of the process.

Post processing is concerned with looking at the results. In the case of the butterfly valve we are looking at the optimisation results and understanding how this affects the design and make up of our carbon fibre plier in manufacturing.

The most powerful piece of FEA is often optimisation. Optimisation is a FEA tool often used within the design process to improve the speed and efficiency of the design. The historical approach would be to create a CAD model, then create prototype tooling and finally test the prototype parts. This would be repeated and re-iterated until a final design is reached. With an optimisation led approach the use of CAD and CAE would allow redesign and assessment very quickly until a final design was reached. This hopefully would mean you would only create one set of prototype tooling. The parts would behave as you would expect, and you could conclude on the design. Optimisation led design will often create more efficient, lighter stronger and more robust designs than the typical, historical approach.

Optimisation requires three main components. Variables, objectives and constraints. In the case of the butterfly valve we are optimising the disk to make the part as light as possible whilst ensuring a stiffness underload. The variable is the 'make-up' or direction, and thickness of the carbon fibre plies. The objective is to make the part as light as possible and the constraint is to ensure the part does not deflect more than 0.1mm under maximum loading conditions. By using CAE the program will look at where the regions of maximum deflection are and adjusting thicknesses and orientation of plies, reiterate the design until it converges on the best possible solution.

FEA and CAE should not always be used however. Where the model or design is lacking complexity, such as with bending moments. Simple hand calculation would be much faster and less time consuming in this scenario. FEA and CAE shines in development where designs are complex, and the engineers are looking for the most efficient way to solve a particular problem.

Typically, the use of FEA and CAE is a balance between accuracy and time. The greater the accuracy often, the longer the solve time. As element sizes are reduced and the elements are changed to second order elements, the degrees of freedom and number of elements drastically increase. As such the solve time increases greatly. There may be a time constraints on a project that does not facilitate these large solves.

Typically to overcome these obstacles engineers would employ a number of tactics to ensure the greatest accuracy in the smallest amount of time. Meshing is often experienced led but there are a number of methods that can improve the solve time vs accuracy problem.

One of the methods employed by engineers is to clean up the model geometry. For example, where holes, embossed logos, fillets, etc. are used, these can be cleaned up so that the mesh does not create a large amount of elements around these complex structures. This however does have its drawbacks. By creating two separate files, (the final part and the CAE part) the time required for modelling

increases. This also brings about issues with version control. The CAE model is now different than the CAD model. As adjustments and updates are made to the CAD model the CAE model must also be updated, this doubles the work required moving forward and risks out of date models/information.

Another technique used by engineers is to run a standard mesh and solve. Once the parts has been analysed for areas of interest. The engineers can go back in and create smaller meshing in these areas to give more accuracy.

In the past a great deal of time has been required for this pre-processing. In some cases engineers have used the symmetry of the part to their advantage. By only using FEA/CAE and optimisation on smaller 'part models' the solve time can be reduced.

As technology and computing power has developed, the requirement for exporting large files for solves and pre processing is reducing. As computing power has increased and software has become more intelligent, using the automatic mesher with a full model is often more efficient than using engineering techniques to reduce the number of elements and solve time.

In the future, the assumption could be made that as technology develops and becomes more intelligent alongside computing power increases, the need for applying engineering techniques will become obsolete. The automated meshing will continue to develop further and computing power will increase. With the development of quantum computers, large solves that typically would have taken days in the past, will be solved almost instantaneously. Meshing will not need adjustment and the accuracy can be ramped up without the worry of solve time.

Additionally, with topology optimisation and 3D printing or additive manufacturing becoming more accessible, the efficiency of designs will continue to improve toward more organic type structures that only have material and strength where required.

Part 2 – Single analysis of design

Create a model of the plate with the correct material properties in Design Studio. Lay this up with 25 plies of the UD. 5 at -90 degrees, 5 plies at -45 degrees, 5 plies at 0 degrees, 5 plies at 45 degrees and 5 plies at 90 degree

Applied Force

To lay up the initial structure we must first understand the forces applied to the valve. As the height of the tank is 5m, the gravity is 9.81m/s and for this scenario we will take the density of water at 1000kg. Pressure is ρgh . As such the pressure 49,050 pascals or 0.49 bar. Assuming a factor of safety of 2. Pressure = 2bar

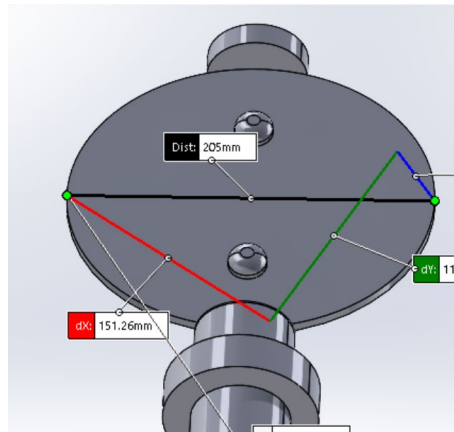


Figure 1 - Diameter of disk

$$Force = Pressure \times Area$$

$$Area = \pi r^2$$

$$Force = 100,000 \times 3.14 \times .1025^2$$

$$Force = 3298.963N$$

$$Magnitude = \frac{Force}{No \text{ of grids}}$$

$$Magnitude = 3298.963/1438$$

$$Magnitude = 2.295N \text{ (rounded up)}$$

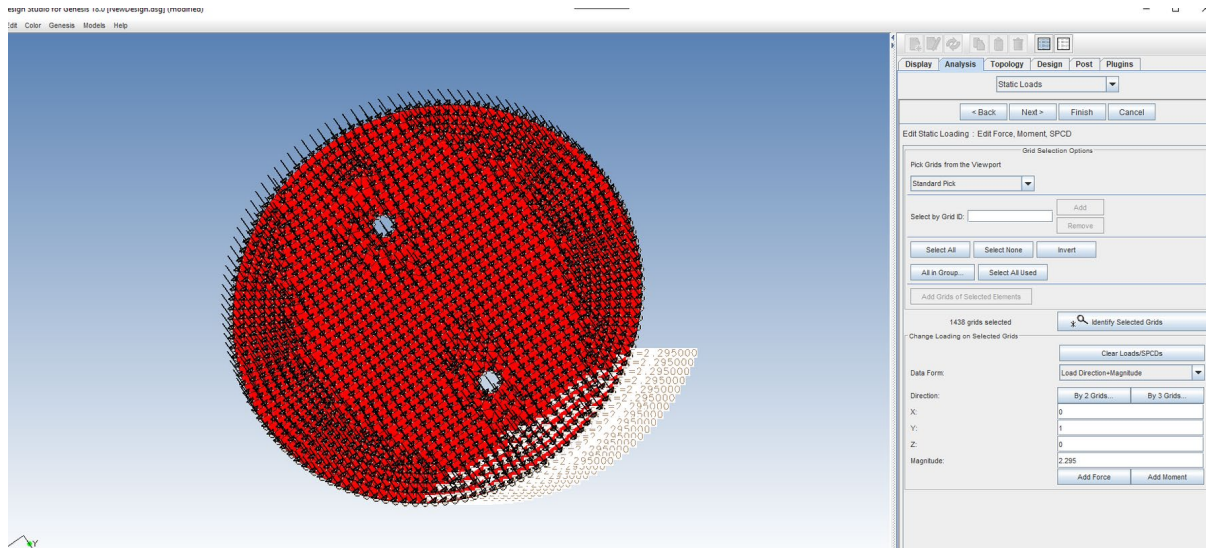


Figure 2 - Forces applied to disk

Baseline Structure - Steel

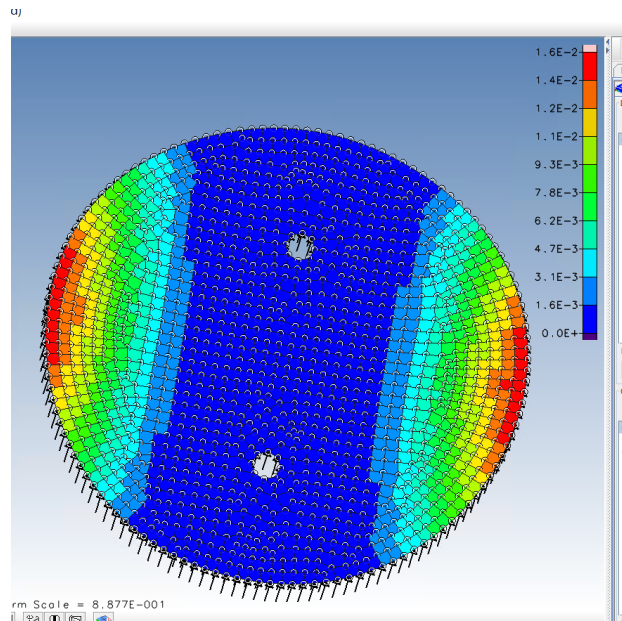


Figure 3- Steel Baseline

Single analysis – Lay up

Single analysis of carbon fibre laid up with 25 plies of the UD. 5 at -90 degrees, 5 plies at -45 degrees, 5 plies at 0 degrees, 5 plies at 45 degrees and 5 plies at 90 degree

[CarbonFibre151021c - Copy.dsg] (modified)

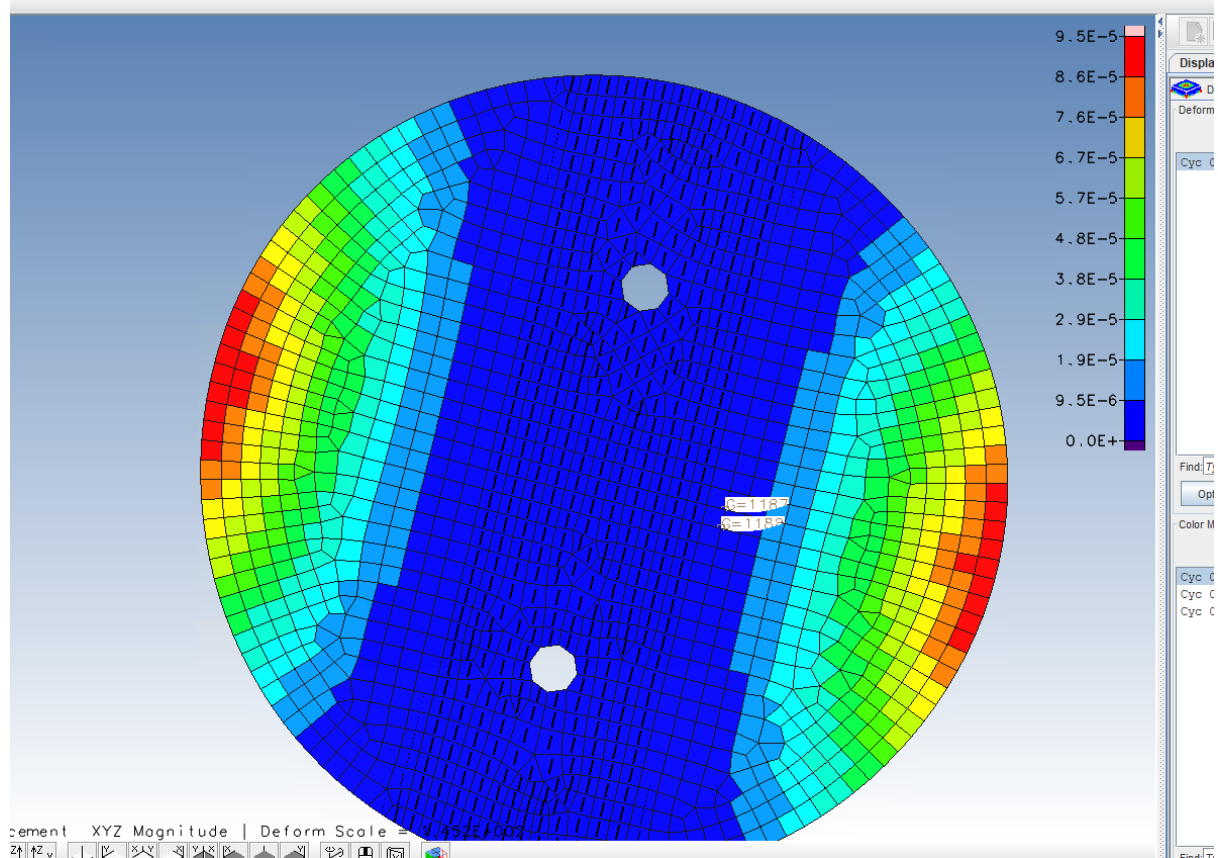


Figure 4 - Arbitrarily laid up composite

As we can see the part deforms at 0.00095mm and this is below the maximum deflection required for the part. The part is very strong but there is a large weight saving that can be made here.

Part 3 – Optimised design

Optimise the structure to minimise the mass of the plate whilst meeting the displacement constraint. Your variables are the number of plies at each orientation. These plies can be placed at -90 degrees, -45 degrees, zero degrees, 45 degrees and 90 degrees

Optimised real variables

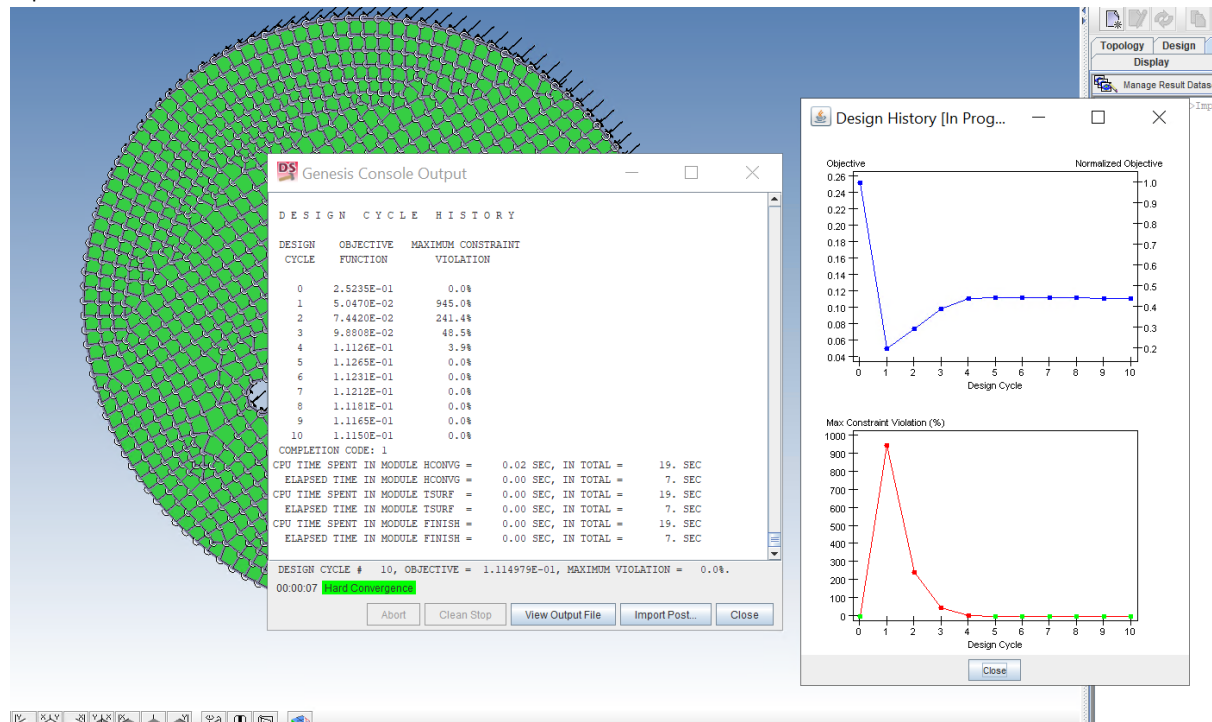


Figure 5 - Optimised design real variables

The data can be read as below.

```

DESIGN CYCLE #    0, OBJECTIVE = 2.523485E-01, MAXIMUM VIOLATION = 0.0%.
DESIGN VARIABLE #    1 = 1.000000E-03    L1THK
DESIGN VARIABLE #    2 = 1.000000E-03    L2THK
DESIGN VARIABLE #    3 = 1.000000E-03    L3THK

DESIGN VARIABLE #    5 = 1.000000E-03    L5THK
DESIGN CYCLE #    1, OBJECTIVE = 5.046971E-02, MAXIMUM VIOLATION = 945.0%.
DESIGN VARIABLE #    1 = 2.000000E-04    L1THK
DESIGN VARIABLE #    2 = 2.000000E-04    L2THK
DESIGN VARIABLE #    3 = 2.000000E-04    L3THK
DESIGN VARIABLE #    4 = 2.000000E-04    L4THK
DESIGN VARIABLE #    5 = 2.000000E-04    L5THK
DESIGN CYCLE #    2, OBJECTIVE = 7.441962E-02, MAXIMUM VIOLATION = 241.4%.
DESIGN VARIABLE #    1 = 3.208154E-04    L1THK
DESIGN VARIABLE #    2 = 2.776081E-04    L2THK
DESIGN VARIABLE #    3 = 2.771766E-04    L3THK
DESIGN VARIABLE #    4 = 2.773546E-04    L4THK
DESIGN VARIABLE #    5 = 3.215856E-04    L5THK
DESIGN CYCLE #    3, OBJECTIVE = 9.880818E-02, MAXIMUM VIOLATION = 48.5%.
  
```

```

DESIGN VARIABLE #      1 = 4.570022E-04      L1THK
DESIGN VARIABLE #      2 = 3.473973E-04      L2THK
DESIGN VARIABLE #      3 = 3.471629E-04      L3THK
DESIGN VARIABLE #      4 = 3.468581E-04      L4THK
DESIGN VARIABLE #      5 = 4.593515E-04      L5THK
DESIGN CYCLE #      4, OBJECTIVE = 1.112636E-01, MAXIMUM VIOLATION =
3.9%.
DESIGN VARIABLE #      1 = 5.411111E-04      L1THK
DESIGN VARIABLE #      2 = 3.730681E-04      L2THK
DESIGN VARIABLE #      3 = 3.739043E-04      L3THK
DESIGN VARIABLE #      4 = 3.721763E-04      L4THK
DESIGN VARIABLE #      5 = 5.443018E-04      L5THK
DESIGN CYCLE #      5, OBJECTIVE = 1.126528E-01, MAXIMUM VIOLATION =
0.0%.
DESIGN VARIABLE #      1 = 5.719196E-04      L1THK
DESIGN VARIABLE #      2 = 3.612319E-04      L2THK
DESIGN VARIABLE #      3 = 3.633278E-04      L3THK
DESIGN VARIABLE #      4 = 3.601096E-04      L4THK
DESIGN VARIABLE #      5 = 5.754986E-04      L5THK
DESIGN CYCLE #      6, OBJECTIVE = 1.123126E-01, MAXIMUM VIOLATION =
0.0%.
DESIGN VARIABLE #      1 = 5.899295E-04      L1THK
DESIGN VARIABLE #      2 = 3.466274E-04      L2THK
DESIGN VARIABLE #      3 = 3.496986E-04      L3THK
DESIGN VARIABLE #      4 = 3.453058E-04      L4THK
DESIGN VARIABLE #      5 = 5.937850E-04      L5THK
DESIGN CYCLE #      7, OBJECTIVE = 1.121198E-01, MAXIMUM VIOLATION =
0.0%.
DESIGN VARIABLE #      1 = 6.081001E-04      L1THK
DESIGN VARIABLE #      2 = 3.329825E-04      L2THK
DESIGN VARIABLE #      3 = 3.365666E-04      L3THK
DESIGN VARIABLE #      4 = 3.315545E-04      L4THK
DESIGN VARIABLE #      5 = 6.123234E-04      L5THK
DESIGN CYCLE #      8, OBJECTIVE = 1.118091E-01, MAXIMUM VIOLATION =
0.0%.
DESIGN VARIABLE #      1 = 6.257027E-04      L1THK
DESIGN VARIABLE #      2 = 3.190318E-04      L2THK
DESIGN VARIABLE #      3 = 3.225045E-04      L3THK
DESIGN VARIABLE #      4 = 3.176849E-04      L4THK
DESIGN VARIABLE #      5 = 6.304465E-04      L5THK
DESIGN CYCLE #      9, OBJECTIVE = 1.116538E-01, MAXIMUM VIOLATION =
0.0%.
DESIGN VARIABLE #      1 = 6.419718E-04      L1THK
DESIGN VARIABLE #      2 = 3.069951E-04      L2THK
DESIGN VARIABLE #      3 = 3.108946E-04      L3THK
DESIGN VARIABLE #      4 = 3.054540E-04      L4THK
DESIGN VARIABLE #      5 = 6.469775E-04      L5THK
DESIGN CYCLE #     10, OBJECTIVE = 1.114979E-01, MAXIMUM VIOLATION =
0.0%.
DESIGN VARIABLE #      1 = 6.566368E-04      L1THK      -90
DESIGN VARIABLE #      2 = 2.960782E-04      L2THK      -45
DESIGN VARIABLE #      3 = 3.001749E-04      L3THK       0
DESIGN VARIABLE #      4 = 2.943918E-04      L4THK      45
DESIGN VARIABLE #      5 = 6.619228E-04      L5THK      90
COMPLETION CODE: 1      1495      0

```

The final thickness to ensure a maximum deflection of 0.1mm are 0.66mm at -90, 0.297mm at -45, 0.3mm at 0, 0.294mm at 45 and 0.662mm at 90. This of course is not manufacturable as the carbon fibre layers are only available at 0.2mm increments. As such we need to solve for discrete data.

The minimum weight is close to 0.111g s below.

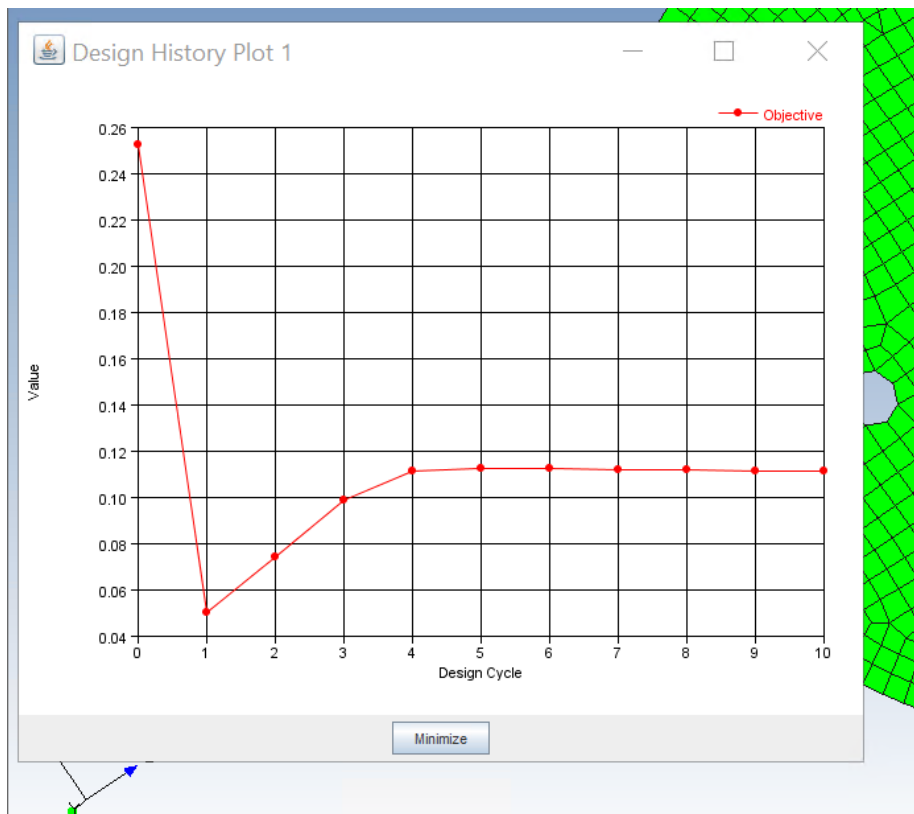


Figure 6 - Design History Objective (Variable data)

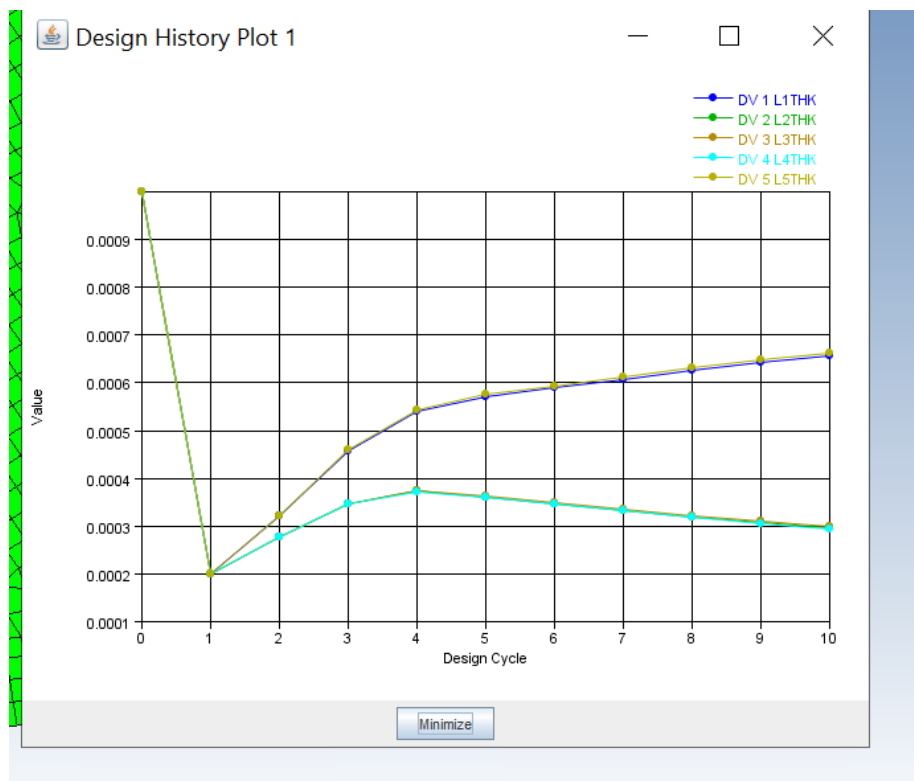


Figure 7 - Optimised Thickness (Variable data)

Optimised Discrete Data

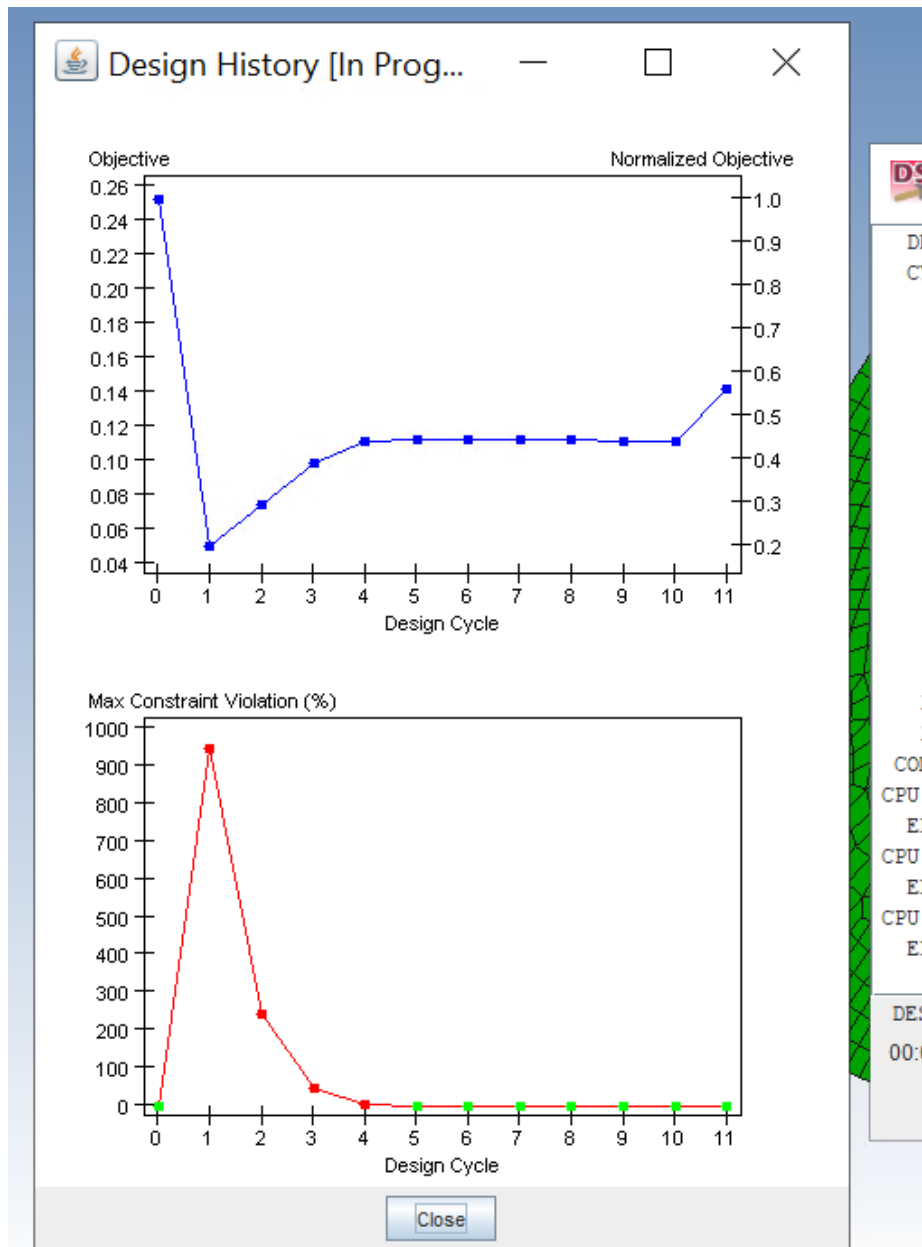


Figure 8 - Optimised design variables (Discrete data)

As we can see from the above image the software solves and at the final cycle it changes the data to discrete data.

```

DESIGN CYCLE #    0, OBJECTIVE =  2.523485E-01, MAXIMUM VIOLATION =    0.0%.
DESIGN VARIABLE #      1 =  1.000000E-03    L1THK
DESIGN VARIABLE #     11 =  1.000000E-03    L2THK
DESIGN VARIABLE #     12 =  1.000000E-03    L3THK

DESIGN VARIABLE #     14 =  1.000000E-03    L5THK
DESIGN CYCLE #     1, OBJECTIVE =  5.046971E-02, MAXIMUM VIOLATION =
945.0%.
DESIGN VARIABLE #      1 =  2.000000E-04    L1THK
DESIGN VARIABLE #     11 =  2.000000E-04    L2THK
DESIGN VARIABLE #     12 =  2.000000E-04    L3THK
    
```

```

DESIGN VARIABLE #      13 = 2.000000E-04      L4THK
DESIGN VARIABLE #      14 = 2.000000E-04      L5THK
DESIGN CYCLE #    2, OBJECTIVE = 7.441962E-02, MAXIMUM VIOLATION =
241.4%.
DESIGN VARIABLE #      1 = 3.208154E-04      L1THK
DESIGN VARIABLE #     11 = 2.776081E-04      L2THK
DESIGN VARIABLE #     12 = 2.771766E-04      L3THK
DESIGN VARIABLE #     13 = 2.773546E-04      L4THK
DESIGN VARIABLE #     14 = 3.215856E-04      L5THK
DESIGN CYCLE #    3, OBJECTIVE = 9.880818E-02, MAXIMUM VIOLATION =
48.5%.
DESIGN VARIABLE #      1 = 4.570022E-04      L1THK
DESIGN VARIABLE #     11 = 3.473973E-04      L2THK
DESIGN VARIABLE #     12 = 3.471629E-04      L3THK
DESIGN VARIABLE #     13 = 3.468581E-04      L4THK
DESIGN VARIABLE #     14 = 4.593515E-04      L5THK
DESIGN CYCLE #    4, OBJECTIVE = 1.112636E-01, MAXIMUM VIOLATION =
3.9%.
DESIGN VARIABLE #      1 = 5.411111E-04      L1THK
DESIGN VARIABLE #     11 = 3.730681E-04      L2THK
DESIGN VARIABLE #     12 = 3.739043E-04      L3THK
DESIGN VARIABLE #     13 = 3.721763E-04      L4THK
DESIGN VARIABLE #     14 = 5.443018E-04      L5THK
DESIGN CYCLE #    5, OBJECTIVE = 1.126528E-01, MAXIMUM VIOLATION =
0.0%.
DESIGN VARIABLE #      1 = 5.719196E-04      L1THK
DESIGN VARIABLE #     11 = 3.612319E-04      L2THK
DESIGN VARIABLE #     12 = 3.633278E-04      L3THK
DESIGN VARIABLE #     13 = 3.601096E-04      L4THK
DESIGN VARIABLE #     14 = 5.754986E-04      L5THK
DESIGN CYCLE #    6, OBJECTIVE = 1.123126E-01, MAXIMUM VIOLATION =
0.0%.
DESIGN VARIABLE #      1 = 5.899295E-04      L1THK
DESIGN VARIABLE #     11 = 3.466274E-04      L2THK
DESIGN VARIABLE #     12 = 3.496986E-04      L3THK
DESIGN VARIABLE #     13 = 3.453058E-04      L4THK
DESIGN VARIABLE #     14 = 5.937850E-04      L5THK
DESIGN CYCLE #    7, OBJECTIVE = 1.121198E-01, MAXIMUM VIOLATION =
0.0%.
DESIGN VARIABLE #      1 = 6.081001E-04      L1THK
DESIGN VARIABLE #     11 = 3.329825E-04      L2THK
DESIGN VARIABLE #     12 = 3.365666E-04      L3THK
DESIGN VARIABLE #     13 = 3.315545E-04      L4THK
DESIGN VARIABLE #     14 = 6.123234E-04      L5THK
DESIGN CYCLE #    8, OBJECTIVE = 1.118091E-01, MAXIMUM VIOLATION =
0.0%.
DESIGN VARIABLE #      1 = 6.257027E-04      L1THK
DESIGN VARIABLE #     11 = 3.190318E-04      L2THK
DESIGN VARIABLE #     12 = 3.225045E-04      L3THK
DESIGN VARIABLE #     13 = 3.176849E-04      L4THK
DESIGN VARIABLE #     14 = 6.304465E-04      L5THK
DESIGN CYCLE #    9, OBJECTIVE = 1.116538E-01, MAXIMUM VIOLATION =
0.0%.
DESIGN VARIABLE #      1 = 6.419718E-04      L1THK
DESIGN VARIABLE #     11 = 3.069951E-04      L2THK
DESIGN VARIABLE #     12 = 3.108946E-04      L3THK
DESIGN VARIABLE #     13 = 3.054540E-04      L4THK
DESIGN VARIABLE #     14 = 6.469775E-04      L5THK
DESIGN CYCLE #   10, OBJECTIVE = 1.114979E-01, MAXIMUM VIOLATION =
0.0%.
DESIGN VARIABLE #      1 = 6.566368E-04      L1THK

```

```

DESIGN VARIABLE #      11 = 2.960782E-04      L2THK
DESIGN VARIABLE #      12 = 3.001749E-04      L3THK
DESIGN VARIABLE #      13 = 2.943918E-04      L4THK
DESIGN VARIABLE #      14 = 6.619228E-04      L5THK
DESIGN CYCLE #    11, OBJECTIVE = 1.413152E-01, MAXIMUM VIOLATION =
0.0%.
DESIGN VARIABLE #          1 = 8.000000E-04      L1THK      -90
DESIGN VARIABLE #      11 = 4.000000E-04      L2THK      -45
DESIGN VARIABLE #      12 = 4.000000E-04      L3THK       0
DESIGN VARIABLE #      13 = 4.000000E-04      L4THK      45
DESIGN VARIABLE #      14 = 8.000000E-04      L5THK      90
COMPLETION CODE: 1      1498      0

```

The final thickness to ensure a maximum deflection of 0.1mm are 0.8mm at -90, 0.4mm at -45, 0.4mm at 0, 0.4mm at 45 and 0.8mm at 90. This is now manufacturable as the carbon fibre layers are available at 0.2mm increments. This change means the design is not completely optimised, meaning it is not as light as possible, but it is as light as it can be to be manufacturable.

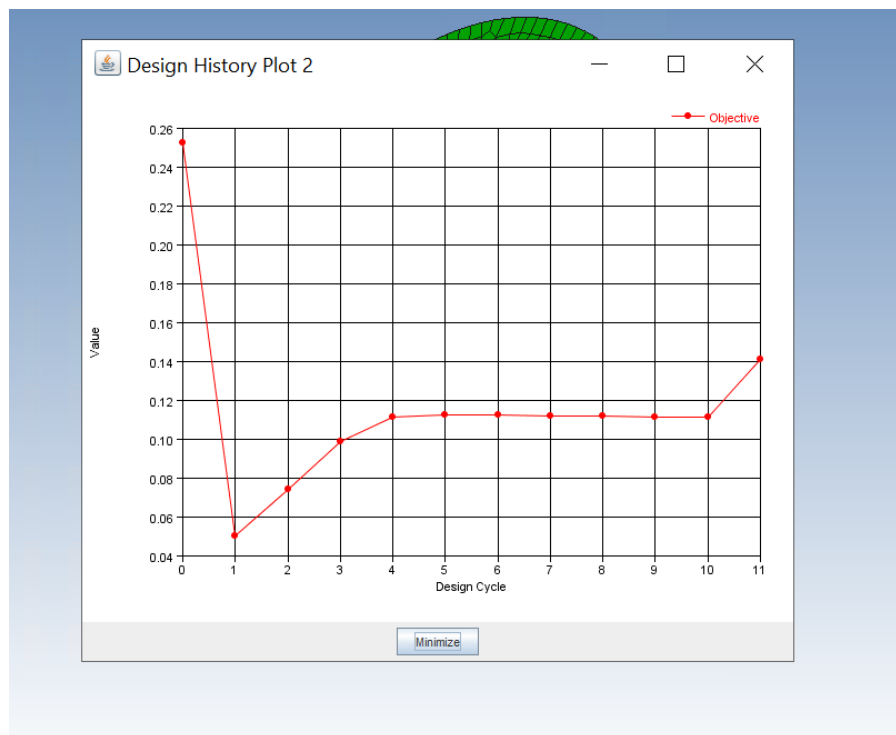


Figure 9 - Objective plot for discrete data

As we can see the weight has increased from 111g to 114g

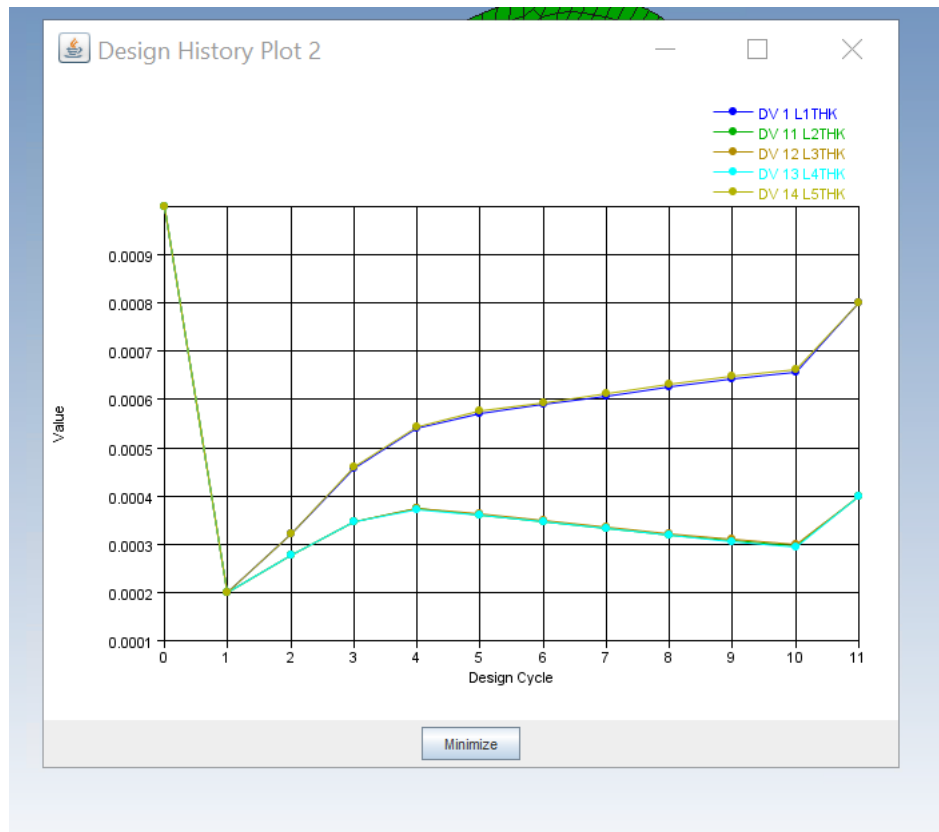


Figure 10 - Discrete data thickness change

Finally we can see graphed, how the thickness per layer has changed with design cycle.

Part 4 – Prototype validation

“During the development of this component, it is proposed that a prototype is produced and tested in a laboratory to understand the deformation of the valve plate when subjected to the hydrostatic forces seen and to correlate it to the simulation carried out in task 3. Discuss how you think this experiment should be carried out and how the acquisition of data should be obtained and compared to the simulation.”

There are a number of methods that could be employed to validate the information and analysis from the optimisation of the component. To validate the design there are two methods that could be employed to ensure it is conforming. The first method that could be used would be to build the valve and leave one of the ends open. As this is a low pressure, hydrostatic test and water can be regarded as incompressible for the purpose of this experiment. This is not a dangerous test. The valve should be filled with water and all air expelled. Close the valve and measure the position of the disk edge using a dial test indicator or DTI. Apply the specified pressure, in this case 1 bar and measure the deflection.

The second method to employ would be by conducting a valve seat test. As we are working under the assumption that for the valve to be leak tight it must not deflect more than 0.1mm. we can conduct a seat test following the requirements laid out in BS 12266 – 1 :2012 – Industrial valves – Testing of metallic valves. The valve has been designed for a rating of 0.5 bar with a factor of safety of 2. As this valve is a prototype, the valve could be tested at differing pressure to understand what point the valve fails pressure test. As stated in (British Standards Institution, 2012)

1. Fill the cavity full with the test fluid. This can be air or water.
2. Move the valve to the closed position
3. Apply the test pressure to the valve for specified duration. (As this is a type test we would apply the pressure for 10 minutes)
4. Determine the leakage rate.

When testing with water we are looking for no visually detectable leakage. This means no weeping or formation of drops. When testing with air, fill the open end of the valve with water so that bubbles are visible if the valve leaks around the periphery.

We could continue to increase the pressure until the valve leaked to determine at what point the valve deforms to the point of failure in seat tightness leakage. This test method could be used in conjunction with the first to validate the deflection of 0.1mm constraint.

Conclusion

The most efficient design to solve this problem is by following the optimisation results using real variables. However, this is not manufacturable as the carbon fibre layers can only be created at a minimum layer thickness of 0.2mm. Thus, the optimisation had to be changed to consider this. The most efficient manufacturable solution for this problem is to lay up the carbon fibre in the following orientations.

-90 degrees – Layer 1 – 0.8mm

-45 degrees – Layer 1 – 0.4mm

0 degrees – Layer 1 – 0.4mm

45 degrees – Layer 1 – 0.4mm

90 degrees – Layer 1 – 0.8mm

References

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