Master's Thesis Engineering Technology

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Optimisation of wheelchairs for Paralympic athletes: design of a flexible carbon fibre backrest

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Master of Electromechanical Engineering Technology

Context

The research lab ICA is working on a global project of designing a wheelchair for a Paralympic badminton athlete. Because this athlete has no abdominal muscles, the backrest of this wheelchair requires elastic bands to support the athlete's back. Each elastic band has a different rigidity. The goal of this master's thesis is to investigate if **the elastic bands could be replicated with thin carbon fibre sheets with a variable rigidity.**

Objective

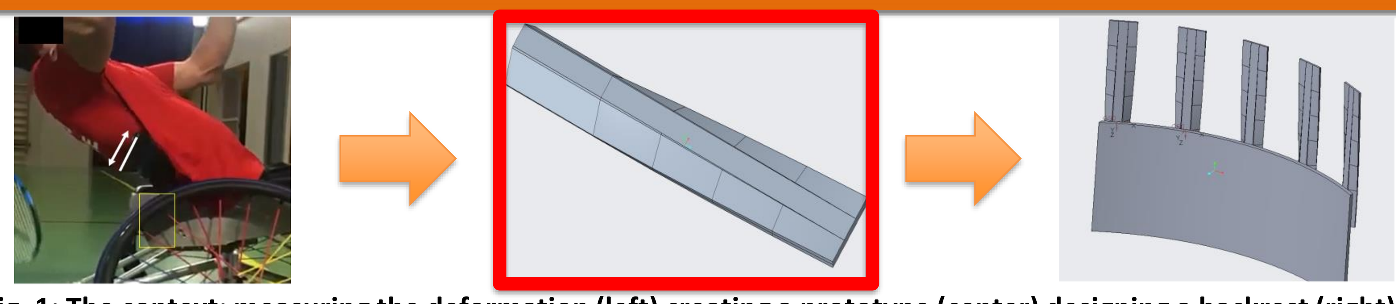

Fig. 1: The context: measuring the deformation (left) creating a prototype (center) designing a backrest (right)

Create a mathematical model for calculating a test sheet to replicate the desired deformation. Using this model, the backrest can be conceived based on the design of this thesis. The calculations and models are made by utilising Microsoft Excel.

Methodology

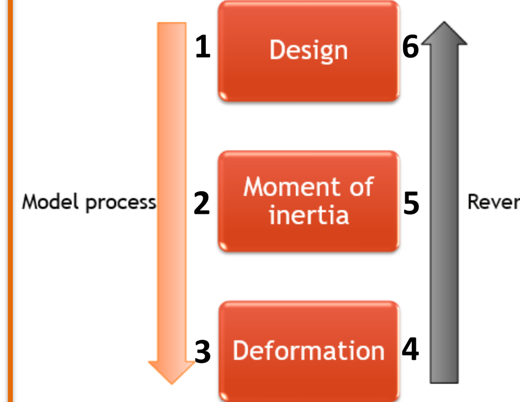

Fig. 2: Methodology schematic

1) Calculate section models for the sheets.
2) Calculate moment of inertia for each section.
3) Check relation between model and deformation.
4) Calculate the desired deformation.
5) Deduce moment of inertia and parameters of the deformation.
6) Create sheet design based on the model and desired deformation.

Successful section models

1) Polynomial model

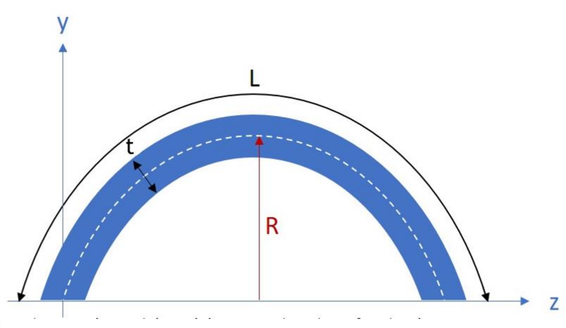

Fig. 3: Representation polynomial model

Constant parameters:

- Section length L
- Thickness t

Variable parameters: radius R

The section model approximates an circular arc. The radius R varies for the sheet.

Result:

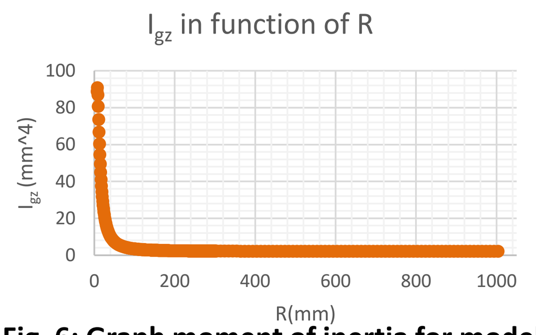

Fig. 6: Graph moment of inertia for model polynomial

Undesirable result:

- A small variation in R results in a large variation of I_{gz}.
- Relation between I_{gz} and R results in complex calculations to find the deformation and create a design.
- The range of I_{gz} is small compared to the other models.

2) U-model

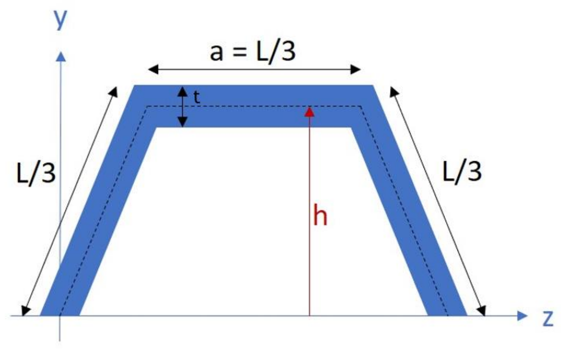

Fig. 4: Representation U-model

Constant parameters:

- Section length L
- Top base a and leg length = L/3
- Thickness t

Variable parameters: height h

The section based on a U. When h decreases, the U folds open.

Result:

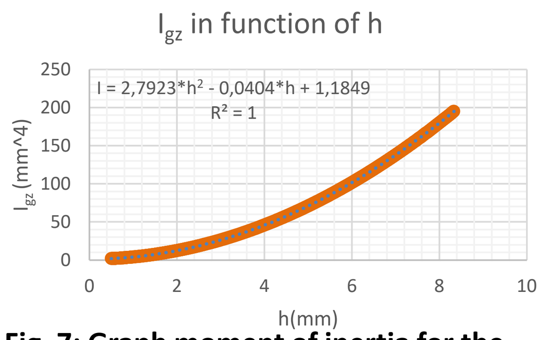

Fig. 7: Graph moment of inertia for the U-model

Desirable result:

- The I_{gz} in function of h is well approximated by a second order polynomial, which makes calculations easier.
- The range of I_{gz} is the biggest compared to the other models.
- **EASIEST MODEL TO USE TO CREATE THE DESIGN**

3) U-model with constant base

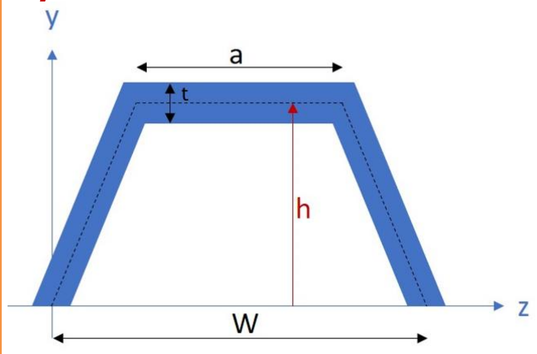

Fig. 5: Representation U-model with constant base

Constant parameters:

- Section length L
- Lower base W
- Thickness t

Variable parameters: height h

The section based on a U with a constant base. When h increases, the top base a decreases.

Result:

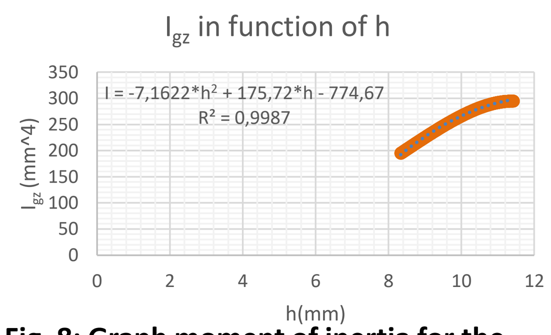

Fig. 8: Graph moment of inertia for the U-model with constant base

Desirable result:

- The I_{gz} in function of h is well approximated by a second order polynomial, which makes calculations easier.
- The range of I_{gz} complements the range for model omega very well, but is superior for the U-model.

Deformation for U-model

Calculating the deformation v(x)

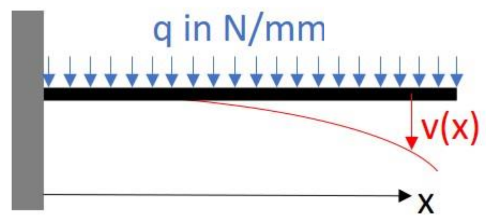

Fig. 9: Schematic representation of the forces on the sheet

The deformation is calculated by the formula:

$$E * I_{gz}(x) * \frac{d^2v(x)}{dx^2} = M(x)$$

Result: Deformation v(x) in function of position x

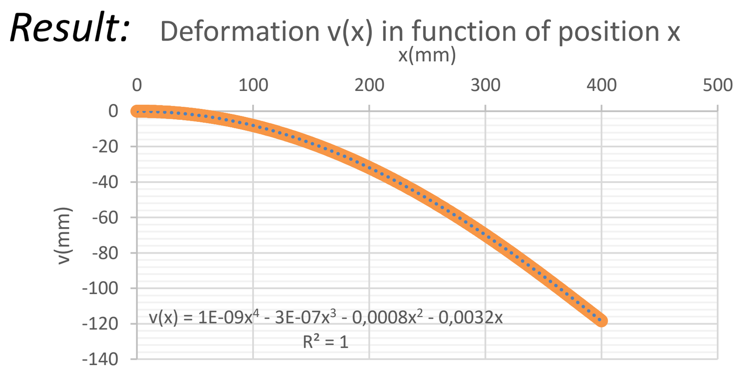

Fig. 10: Graph deformation v(x) in function of x for the U-model

Most important variations of parameters

q
charge

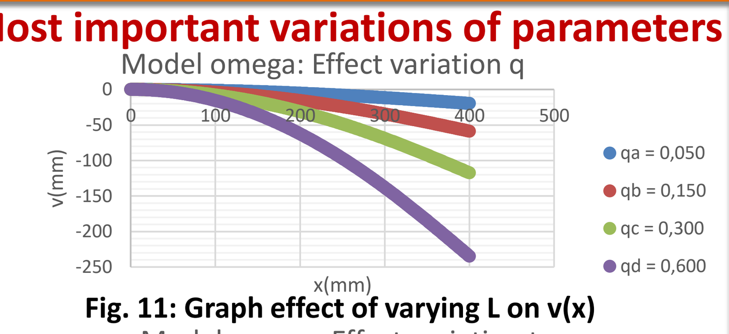

Fig. 11: Graph effect of varying L on v(x)

t
thickness

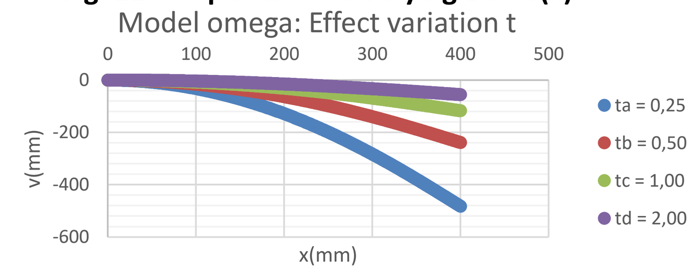

Fig. 12: Graph effect of varying t on v(x)

Δh
h = Δh + t/2

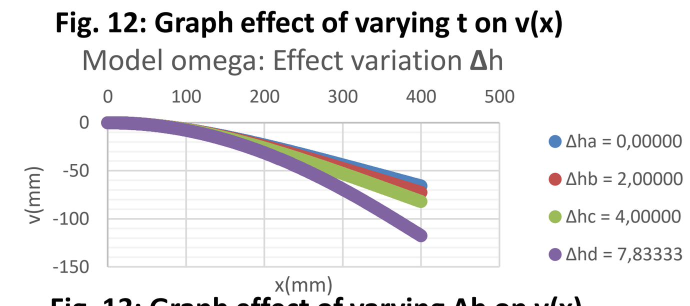

Fig. 13: Graph effect of varying Δh on v(x)

Sheet design

Desired deformation

By measuring the deformation on images of the current backrest, an average deformation (v) of 101 mm is calculated.

Fig. 14: Principle measuring deformations

Design parameters

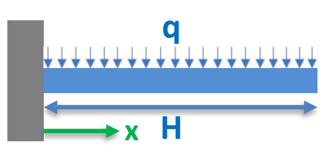

Fig. 15: Shape in length

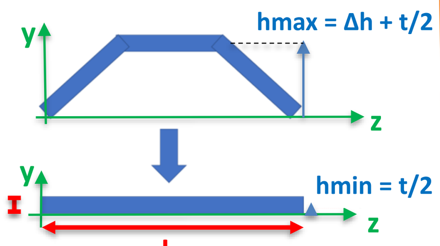

Fig. 16: Variation of the section

Design prototype

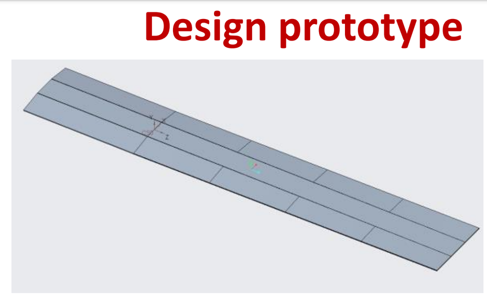

Fig. 17: 3D Prototype design

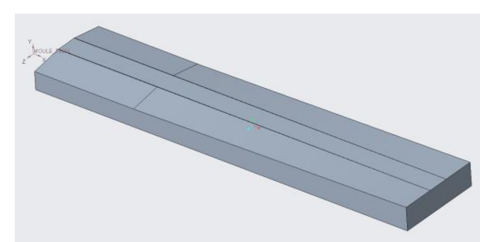

Fig. 18: 3D Mould design

Design parameters:

H = 138 mm
q = 0,3 N/mm
Δh = 1,31 mm
L = 30 mm
t = 0,38 mm
E = 75 GPa

E, q and t estimated on literature and calculations. L and H are based on design constraints. L and Δh are optimised to find v(H) = 101

Finite Element Analysis (FEA) results

Linear FEA deformation for q = 0,3 N/mm

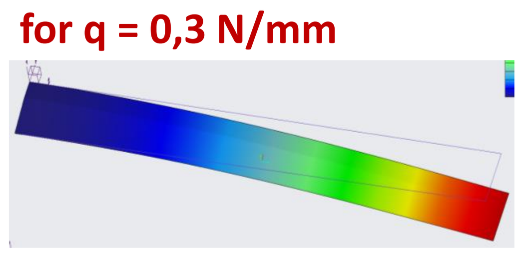

Fig. 19: FEA deformation result

Maximum deformation of the linear FEA is 108 mm. Close to the expected result.

Non-linear FEA deformations

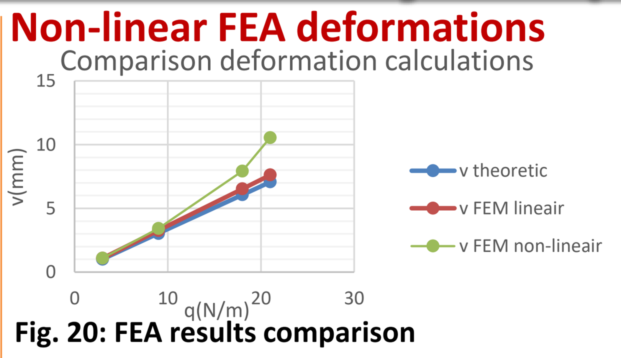

Fig. 20: FEA results comparison

For q>0,021 N/mm, it isn't possible to calculate the non-linear deformation. Limited application for the model.

Linear FEA stress for q = 0,3 N/mm

Table 1: Comparison FEA stress results

Type of stress	Calculated stress (MPa)	FEA stress results (MPa)
Maximum	488	474
Minimum	-976	-933

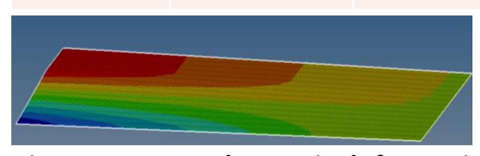

Fig. 21: FEA results z-axis deformation

Conclusions

Conclusions

- The U-model was the easiest, most effective model to create the design. Creating the design with the U-model with constant base by varying parameters was nearly impossible.
- When beam theory is applicable (linear FEM-calculations, small deformation,…), the theoretical model yields favourable results. The model needs to expand to include non-linear deformations.
- Values for t, E and q are estimations. Physical tests should give concrete values for these parameters.

Outlook for future research

- Conduct physical tests of the prototype to check the model parameters and to optimise E and t.
- Conduct 3D scans of the charge and the deformations to adjust/verify the theoretical model.
- Expand the model to include non-linear calculations in function of the position x, shear and time.

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