Fontys School of Engineering

Design of a configurable Spring-Damper using Additive Manufacturing

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Abstract—*This paper describes the results of a second year Expo project team of Fontys Engineering, department Mechanical Engineering. During this research the design of a configurable damped spring design has been investigated. A calculation tool has been defined and validated using a Nylon 3D printed spring prototype. Also a theoretical design of a stainless steel spring has been made including stress calculations. Finally characterization tests on damping properties have been performed.*

Keywords—*Additive Manufacturing, spring, damping, Nylon, Stainless Steel*

INTRODUCTION

Additive Manufacturing (AM), better known as 3D-printing, is an up-and-coming technique for designing and creating a wide variety of products. Whenever we speak of AM, we speak of innovation. The technique is constantly improving in a different ways. Printers are getting faster, new materials are getting implemented and the printers are printing with less flaws in the production process. Because it's a relatively new technique, there is a lot of unknown factors when designing and creating a product.

When designing new systems while using AM, the limitations of the technique need to be taken into consideration. However, there are also a lot of positive factors to it. Mainly being the amount of possibilities available to it. Every shape is possible with a variety of materials available, depending on the type of printer and the materials available. For this project the objective was to design a spring-damper system with the help of Additive Manufacturing. The main goal of this product is to enable a fast definition of different types of damped springs to be used in various applications in High Tech Systems.

This paper describes the first research results into the design of a modular characterised spring/damper system including the opportunities and limitations of the 3D print process. The Objexlab at the Fontys university in Eindhoven was used for information and to print the concepts.

MATERIALS

Introduction

As said before the amount of usable materials are limited because we are using Additive Manufacturing. Because we are printing the concepts at the Fontys Objexlab, the amount of materials are even further limited.

Because of its mechanical properties nylon was a good choice for a first concept. However when 3D printing a spring, there is open space in between the spring. Because of the way AM works, meaning it has layers on top of each other, these spaces need to be filled with supports. A problem occurs when deciding the kind of supports used. The general types of supports used when 3D-printing plastics are supports that dissolve when put in a bath of water. The problem with nylon is that its known to relatively absorb a lot of water and thus will affect the mechanical properties of the spring. However, after some research, the estimated amount of water absorbed will be around 5 percent of the total weight of the spring. the spring's weight will be relatively low, around 10-20 grams, this 5 percent is neglect able.

For the second concept we will be using stainless steel, as that would be the material used in most applications of our product. The problem with printing steel is that it's more brittle than regular steel and it will deform or even collapse when the heat isn't dispensed correctly. To prevent it from deforming or collapsing thermal conductors will need to be added that will be removed when the spring fully cooled down. This will bring extra costs and complications for the printing process.

Nylon

The type of nylon that is used for 3D-printing the Nylon concept is called Taulman Nylon Bridge. We started with a nylon concept to see what parameters we could change to change the spring constant. For this we must look at the mechanical properties of the used nylon first.

Fig. 1. Taulman Nylon Bridge

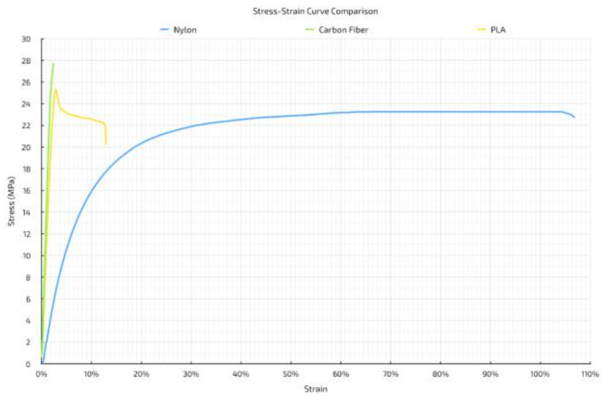

Fig. 2. Comparison of stress-strain graphs of some commonly used materials

In figure 2 some materials that are commonly used are compared.

This material has been created because there was no existing type of nylon that could be 3D printed at the time. There are different versions of it, all existing of polymers or copolymers. The technical numbers for these materials are 618, 645, 645 rev(B) ‘bridge’, 680 and 230. For this research the material 645 rev(B) ‘bridge’has been used. This material is an improved version of nylon 645. The difference is that it’s closer towards the price of current ABS and PLA thermoplastics, while still maintaining the strength of nylon 645. Nylon bridge is an improvement from PLA and ABS in many respects. The main benefits are that nylon bridge is significantly stronger, more durable, it prevents warping, has better adhesion to the bed and is just easier to print. Nylon bridge has been tested by Taulman. The general benefits of Nylon Bridge are high strength, tough, flexible, low weight.

Looking at figure 2 it can be concluded that Nylon has a lot more strain compared to the other two materials, which makes it a good material for a spring that can be made with Additive Manufacturing. The Young’s modulus of this material type resulting from the stress strain analysis is around 185 MPa according to the datasheets.

However seen the importance of the exact value of the Young’s modulus on the spring properties is of high importance abd the 3D printer and printer parameters influences the mechanical properties of a material additional material tests have been performed as part of this research.

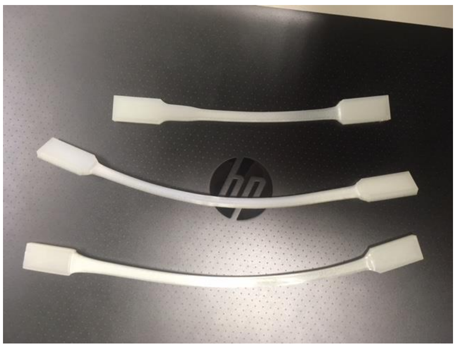

Fig 3: Test specimens

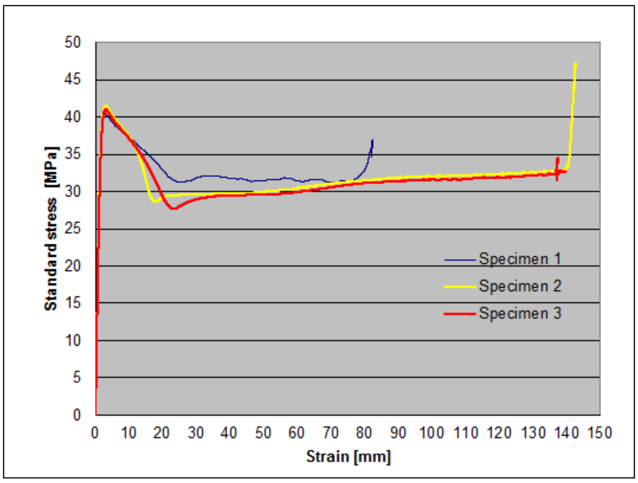

Fig 4: Stress Strain test results

Figure 3 shows different specimens that were tested. In figure 4 the various stress-strain plots are shown.

From these test results an average Young’s modulus of 1050 MPa has been determined. This value is a significant deviation from the value as given by the manufacturer being 185 MPa. For the spring calculation model this value for the Young’s modulus has been used.

Steel

The steel used for this research is 316L stainless steel. 3D printing steel is being done by means of sintering. Sintering is a relatively new technique for AM, where small grains of steel are heated and melted onto each other. Because this is quite a new technique, not a lot of properties are known about the steel after it has cooled down. Using the experience of the Fontys Objexlab it was decided to work with 95% of the standard properties of the steel. The benefits of using this steel is that it’s a stainless steel and thus resistant against corrosion.

However, there are also several challenges when 3D printing steel that need to be taken into account. The first problem is that printing steel is expensive relative to other ways of manufacturing. Another problem is that there need to be two kinds of supports. The first kind is the same as the Nylon concept and is to provide mechanical stability. The second are supports in the form of thermal conductors. Because sintering produces a lot of heat, the heat needs to be removed through these conductors. Since 316L steel has a relative low thermal conductivity, a lot of conductors need to be used that need to be removed after the printing process. However, it is possible to make the design in a way that the first supports conduct heat. Added onto this, supports will also increase the price, making the print more expensive than it already is. Lastly, because of internal tensions and the way the head of the printer moves, the print needs to be made in an angle of 45 degrees.

SPRING DESIGN

Because we have set specifications for our system and also just for our spring, there are limited options for the dimensions. However, there are a couple different ways to influence the spring constant.
There are also constraint, mostly to do with the materials that are useable with AM. Over time these constraints will fade away more and more as the technique improves.

Because we are using Additive Manufacturing, the amount of useable materials is limited. This is important to know, because it means the Young’s modulus is set. This means the only parameters we can change are dimensions of the spring and not the material. However, because the dimensions of the spring have a lot of influence in its parameters, this is not a problem for this type of product.

Specifications

As said before we have set goals for our specifications. The three specifications that have been decided for the spring are:

- Spring constant of around 1-2 N/mm
- Spring stroke of around 10 mm
- Linear spring stroke

Because it’s easy to change the dimensions of the spring with 3D-printing, it is possible to change specifications a lot. To get from a basic concept to a detailed design with the right parameters, we will first need to know how to calculate them.

Calculation model

To gain more insight in the production of 3D-printed springs, a calculation model needs to be defined that can be used to quickly determine the required spring dimensions. In this calculation model it is important to first find the right values of a certain material, the Young’s modulus being the most important one. Because of the way Additive manufacturing works, the Young’s modulus of the material will be different for every type of printer and will also vary when changing printing parameters on a 3D printer.
As outlined earlier the Young’s modulus used for this research has been determined to be 1050 MPa for Nylon. Because 3D printed steel is already being tested at the Fontys Objexlab, the Young’s modulus did not need to be tested. The given Young’s modulus is 180.500 MPa

To calculate the moment in the beam we need to use the Free body diagram, shown in the figure below. To better show the reaction caused by the force and moment, see the figure to the right.

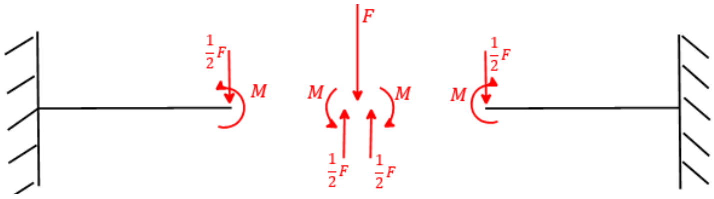

Fig. 5. Free body diagram beam

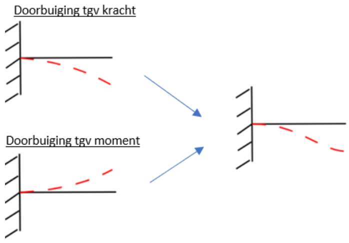

Fig. 6. Reaction caused by the force and moment

Using these figures, the moment can be calculated through the formula below

$$\theta_{tot} = \frac{PL^2}{2EI} - \frac{ML}{EI} = 0 \rightarrow \frac{PL^2}{2EI} = \frac{ML}{EI} \rightarrow M = \frac{PL}{2} \qquad (1)$$

The deflection of the beam can be written as:

$$V_{tot} = \frac{PL^3}{3EI} - \frac{ML^2}{2EI} \qquad (2)$$

Combining (1) and (2) results in:

$$V_{tot} = \frac{PL^3}{3EI} - \frac{PL^3}{4EI} \rightarrow \frac{P}{V_{tot}} = \frac{1}{\frac{L^3}{3EI} - \frac{L^3}{4EI}} \qquad (3)$$

In this formula, $P = \frac{1}{2}F$

When applied, the following formula can be defined:

$$\frac{F}{V_{tot}} = \frac{2}{\frac{L^3}{3EI} - \frac{L^3}{4EI}} \qquad (4)$$

Using the given equations an Excel based calculation model has been made with which the spring constant will be automatically calculated for different parameters of the required spring.

Material stresses

For both the Nylon and steel spring design the bending stresses and shear stresses at maximum spring compression have been calculated using the following equations:

$$\sigma = \frac{My}{I} \qquad (5)$$

$$\tau = \frac{V \times Q}{I \times b} \qquad (6)$$

The resulting stresses are shown in the table below:

Table 1: summary calculated stresses

	Bending stresses [MPa]	**Shear stresses [MPa]**	**Tensile strength material [MPa]**
Nylon	26,9	0,4	41
AISI 316L	612	2,4	515

From these calculations it can be seen that the AISI316L will most likely fail at full compression which means that the design requires an additional iteration step. The Nylon spring will be able to accommodate full compression. The application of these types of spring will mean a cyclic load which means that fatique will alse nee to be taken into consideration.

Dimensions of the Nylon concept

Now we have a way to calculate the properties and we have goal specifications, we can use the calculation sheet to determine these properties. There is however a constraint. Depending on the printer, all parts have to be a minimum thickness. For the printer at the Fontys Objexlab, this minimum is 0,4 mm. However, with a thickness this small, there is still a chance that it will break. That is why it is better to have all parts being thicker than this minumim. As the technique of Additive manufacturing improves, so will this minimum thickness and the chance of errors will be reduced.

The final dimensions of the Nylon spring are seen in the figure on the right. There is a minium thickness of 0,8 on the horizontal beams to ensure that the spring wont break in the process.

If we look at the specifications of the spring, the spring constant can be detirmined by using the formula:

$$k = \frac{F}{u} d \qquad (7)$$

Filling in the parameters F and u we receive the following spring constant: $\frac{38,3}{13,7} = 2,8\ {}^{N}/_{mm}$

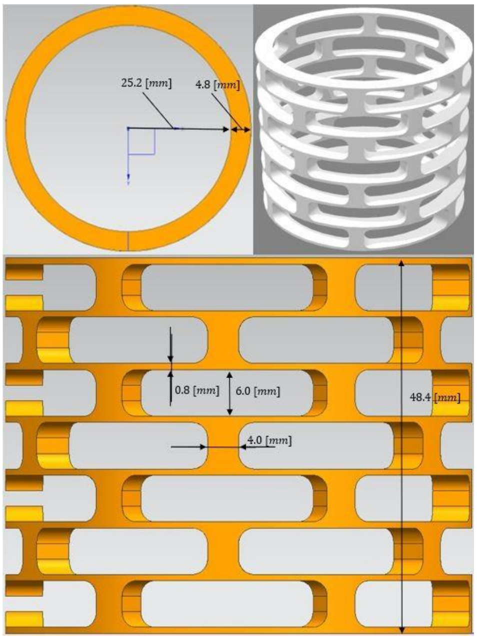

Fig 7: Nylon spring design

Damping and damping integration

Introduction

There are a couple different ways to implement a damper. Because we are working with a spring that has been made by additive manufacturing, there are some ways of damping that will be harder to implement. For example, because a 3D print is hard to get hermetically sealed, damping with air pressure or a form of liquid is not considered.

The target specifications for damping has been set at the beginning of the project on a value of around 0,1-1 N/(m/s). After careful consideration it was decided to use a Viscous elastic material, known as Sorbothane. This material is known to have tough, as well as elastic properties. This means that it will act as a shock-damper for our spring-damper system.

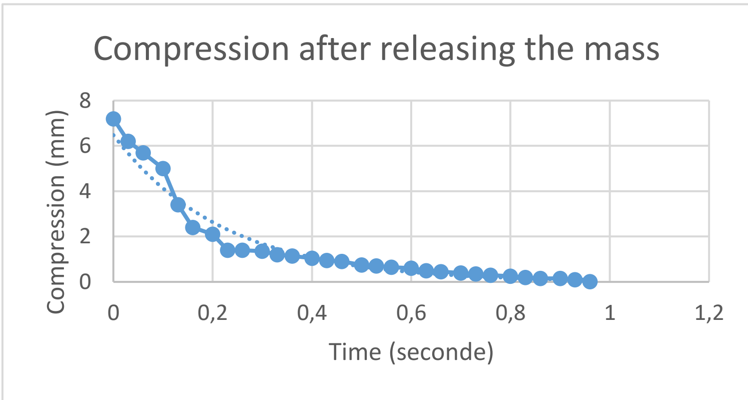

Fig. 8. Compression spring over time

Damping in the Nylon concept

Because of its mechanical properties, Nylon already has a high damping value. To find out the damping for a Nylon printed spring this spring, we ran some tests on the spring without Sorbothane applied. To this end a mass was connected to a prototype spring and the response of this damped mass-spring system has been investigated. Because of the known mass and spring constant, we can determine the damping through using:

$$ms2+cs+k=0 \qquad (8)$$

With the test and the graph created from this test, it can be concluded that the damping is critical or above critical, or in other words overdamped. From here the damping is calculated with the using:

For critical: $k^2 - 4mc = 0$
For overdamped : $k^2 - 4mc < 0$

The mass has been measured and weighs 4,7 kg. The Spring constant has been determined from a previous test and is $6{,}67 * 10^3\ {}^{N}/_{mm}$. The ultimate damping value is $k^2 \leq$ 4mc, which means $k \leq \sqrt{4mc}$.
Filling in the known data, it gives: $k \leq 4 * 4{,}7 * 2{,}67 * 10^3$. This means the damping value is smaller or equal to 224,04 ${}^{kg}/_{s}$
Because of already high value for damping adding of Sorbothane to a Nylon spring design has not been implemented.

Damping in the Steel concept

Since steel has different mechanical properties, the steel spring will not have the same damping characteristics like a Nylon spring. Because of this, Sorbothane will need to be used. Because of this, we need to find a way to connect the Sorbothane to the spring. But first we will need to determine the damping values for Sorbothane.

To test the damping value, we took a string of Sorbothane and hung a mass on it. Seen as a damped mass-spring system once again. Because the mass and spring constant is known, the damping value can be determined with the same formula's as the Nylon spring's damping. The mass weighs 2,2 kg

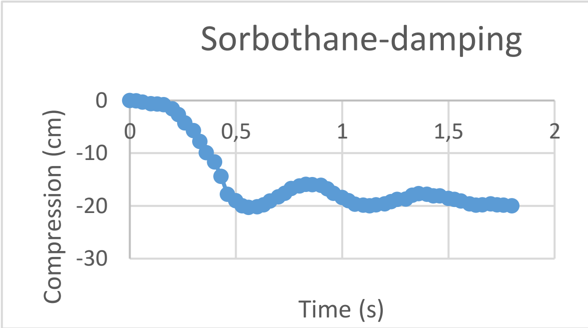

Fig. 9. Sorbothane compression over time

The Spring constant will be determined with the following equation:

$$C = \frac{m*g}{u} = \frac{2{,}2*9{,}81}{0{,}01*(29{,}2-9{,}2)} = 107{,}91\ {}^{N}/_{m} \qquad (9)$$

The damping value is: $k^2 > 4mc$, which means $k > \sqrt{4mc}$. Filled in, this formula gives: $k > \sqrt{4 * 2{,}2 * 107{,}91} = 30{,}82\ {}^{kg}/_{s}$.
This means the damping value is bigger than 30,82 ${}^{kg}/_{s}$

Integrating the Sorbothane to the steel spring

There were a couple different ways to connect the Sorbothane. Since we have a multi layered spring, the best option was to integrate it vertically on the inside and connect it through these layers. This way we can determine the best what the damping value will be while also maintaining ways to change the damping value, if desired.

The way we connected the Sorbothane is displayed on the right. The supports for the Sorbothane have been tested on the Nylon concept.

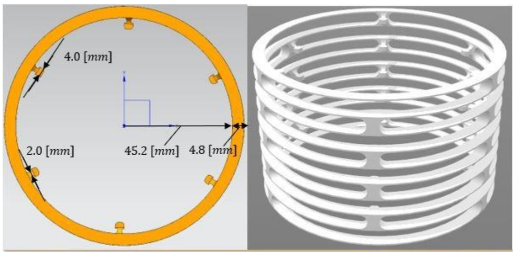

Fig. 10. RVS concept with supports for Sorbothane

Conclusions

Using a simplified force based model a first design of both a Nylon and stainless steel spring for Additive Manufacturing production has been made. The nylon spring has been used successful in order to validate the calculations. Test performed on Nylon specimens have shown a significant deviation with specified values for Young's modulus.

The damping characteristics of Sorbothane have been determined demonstrating that this material can be integrated into a stainless steel spring in order to provide damping.

Stress calculations have shown that an additional design iteration is required to accommodate full spring compression and fatigue limits.

Acknowledgements

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References

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