pulsation in external gear pumps.

DEMCON MULTIPHYSICS

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Goal

External gear pumps are used in the production of rubber tyres. The external gear pump pressurizes the rubber before it is extruded into a long strip. The target is to produce a strip with consistent dimensions. However, the external gear pump introduces a pulsation in the pressure and mass flow that translates to a pulsation in the width and thickness of the extruded rubber strip. This is also shown in the images from figure 2, where the pulsation is exaggerated to show its influence.

The goal of the project is to understand the underlying mechanisms that cause pulsation and to predictably influence the pulsation.

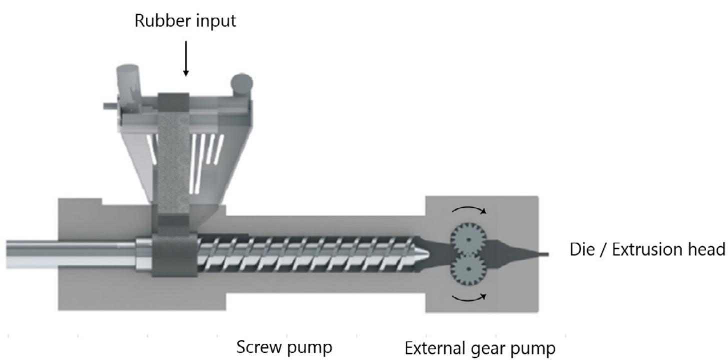

Figure 1 The rubber extrusion machine and the location of the external gear pump in it.

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A literature study on the topic revealed that the pulsation of the external gear pump is caused by its kinematics (i.e. the shape of the gears and its rotational velocity) and influenced by the fluid dynamics (i.e. viscosity, compressibility etc. of the rubber).

Remeshing the geometry for each timestep proved to be very time consuming in both mesh time and simulation time. Additionally the quality of the mesh was not good enough to resolve the high gradients of pressure and velocity between the teeth.

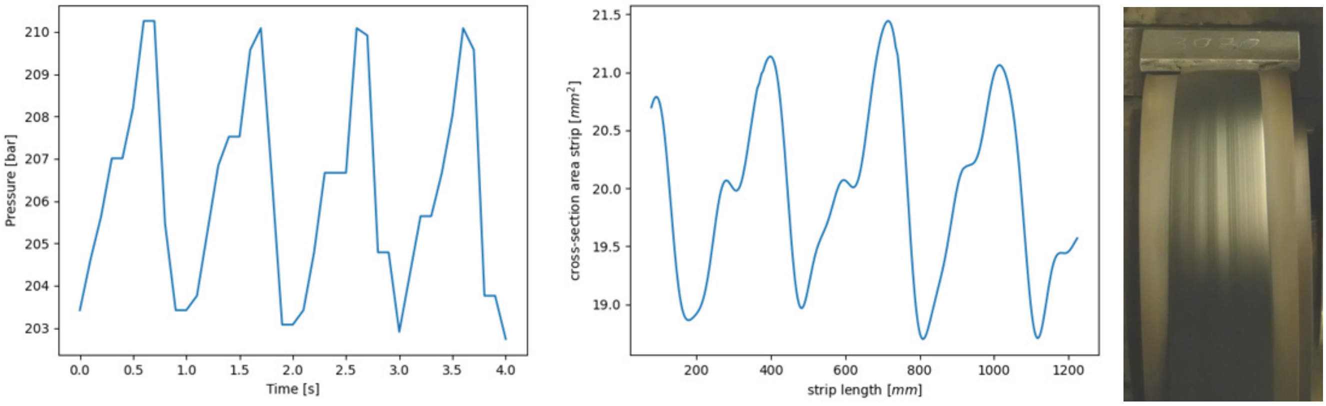

Figure 2 The pulsation in pressure caused by the external gear pump and the resulting similar pulsation in the cross sectional area of the strip.

Since the preference was to not change the shape of the gear, the rotational velocity of the gears is adapted using several periodic velocity curves as input. These input curves are tested using both CFD and experimentally, and the results are compared.

CFD approach

The CFD simulation is performed in 2D, to keep simulation times low. The domain is shown in figure 3 and is based on the geometry of the machine the experiments are performed on. A porous domain with a high resistance is added to the end of the domain to simulate the resistance caused by the extrusion head of the machine.

One of the main challenges of the CFD simulation was the mesh. Normally a stationary and rotating mesh combination is used for rotating geometries, but this approach is not possible as the two gears mesh together.

To solve this, the meshing software TwinMesh was used. Using TwinMesh we were able to create a structured mesh for each gear, that is 'compressed' between the teeth. The structure and element numbering is kept exactly the same between timesteps, only the rotation and compression is changed. This ensures that the simulation doesn't need to interpolate the results of the previous timestep on a new grid, which greatly increases the accuracy and speed of the simulation.

Also the fluid behaviour of rubber needed some extra attention in this simulation. Rubber is non-Newtonian, which means that its viscosity changes with differing shear stress, pressure and temperature. This was all added to the material model, and special care was taken in velocity-pressure coupling in the solver to prevent instabilities due to the high gradients. Lastly, the flow has a very low Reynolds number, and is thus modelled as laminar flow.

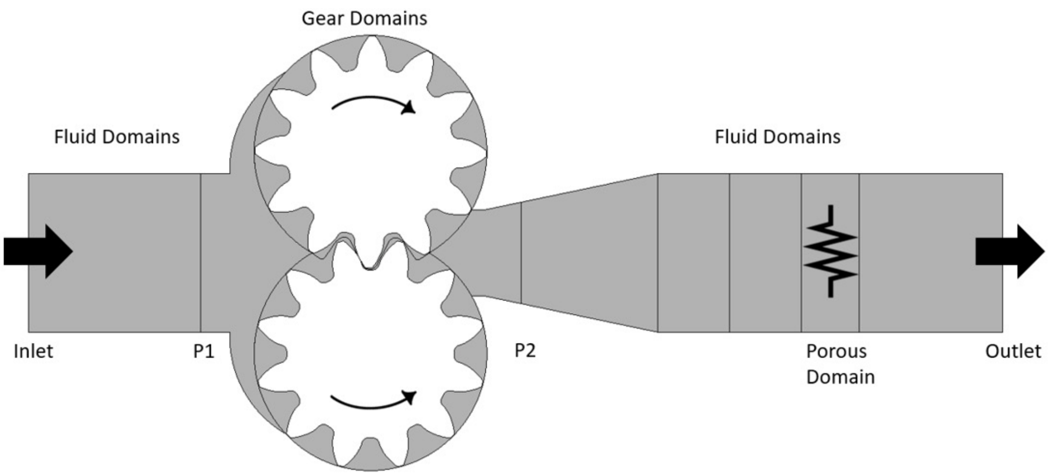

Figure 3 The domain used in the CFD simulation.

Experimental approach

The experimental set-up is a similar machine as was shown in Figure 1, the external gear pump is shown more detailed in Figure 4. The pressure sensors in the machine corresponds to the location where pressure is measured in the CFD simulation. The same velocity input curves are used in the experiments and the CFD simulations, and two different rubber compounds were used that have different non-Newtonian behaviours.

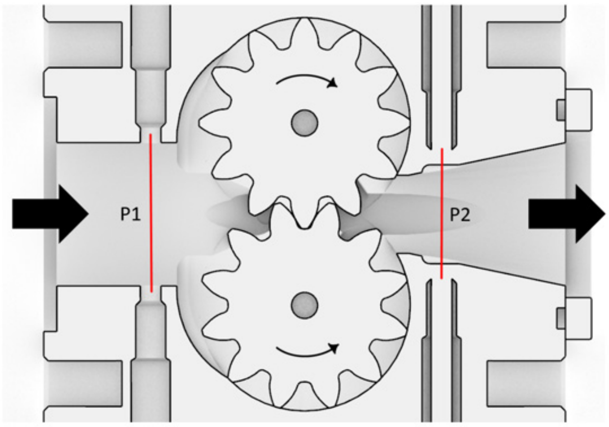

Figure 4 The external gear pump used in the experiments. P1 and P2 are pressure sensors.

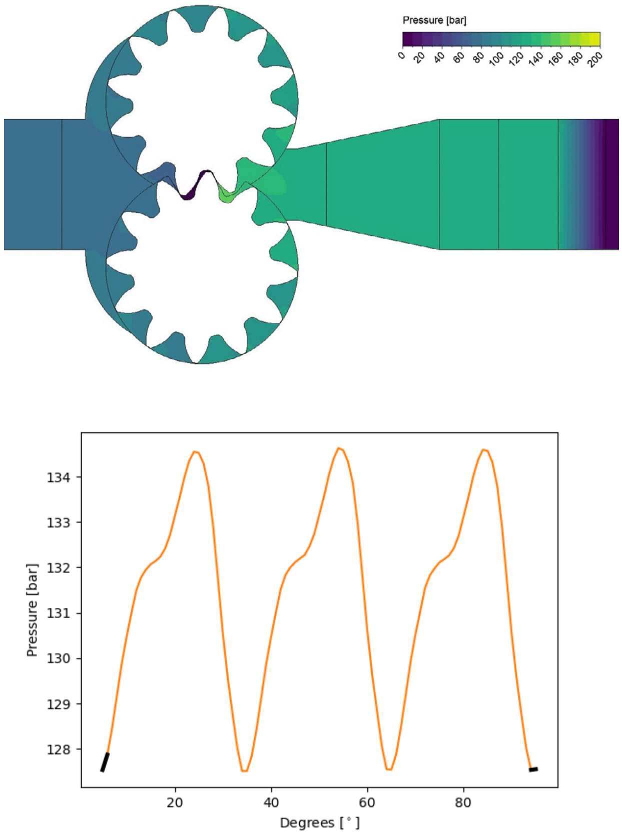

Figure 5 CFD results of the external gear pump. The pressure in the domain and the pressure at the outlet are shown.

Results

Figure 5 is a snapshot from an animation, which can be found on our website. We can see the working principle of the external gear pump quite nicely in the results: a lower pressure rubber is fed into the pump on the top panel in figure 6. As the gears rotate, rubber is taken via the outside of the pump to the higher pressure side of the pump. The teeth then mesh and the rubber is pressed out from between the teeth and towards the outlet. The periodicity of the meshing teeth can be seen on the bottom panel in figure 5. It shows the resulting pressure curve at the outlet, and looks very similar to the measured pressure and cross-sectional area curves that were shown in Figure 2.

That simulation was done using a constant rotational velocity for the gears. More interesting of course is what happens when the rotational velocity is changed periodically to change the resulting pulsation. Several input curves where tested, the triangle-shaped input curve is shown in figure 6 as illustration.

In the plots we see the pressure/cross-sectional area pulsation for constant rotational velocity in blue, with the simulation on the left and the experimental data of 3 separate runs on the right. Both plots are non-dimensionalized and normalized to an amplitude of 1 [-], to enable comparison between the two data sets.

Then the triangle velocity input curve (VIC) is used, the shape and timing of the input curve is shown using the grey line in the left plot. The resulting pulsation is again shown, this time in orange. As can be seen the amplitude and shape of the pulsation change very similarly in both the experimental data and the simulation. As such it was concluded that the simulation can be used to predict the behaviour of the pulsation, and can thus give an indication of the quality of the extruded rubber strip before any experiments need to be performed. This simplifies the design process quite a bit, and can save a lot of money in both man and machine hours!

Conclusion and outlook

In this project it was shown what influences and causes the pulsation of external gear pumps. Additionally an approach to changing the resulting pulsation was proposed, tested and validated. The next step in the process would be to create an input curve that virtually eliminates this pulsation. This could increase the quality of rubber strips and the efficiency of tyres, reducing its carbon footprint.

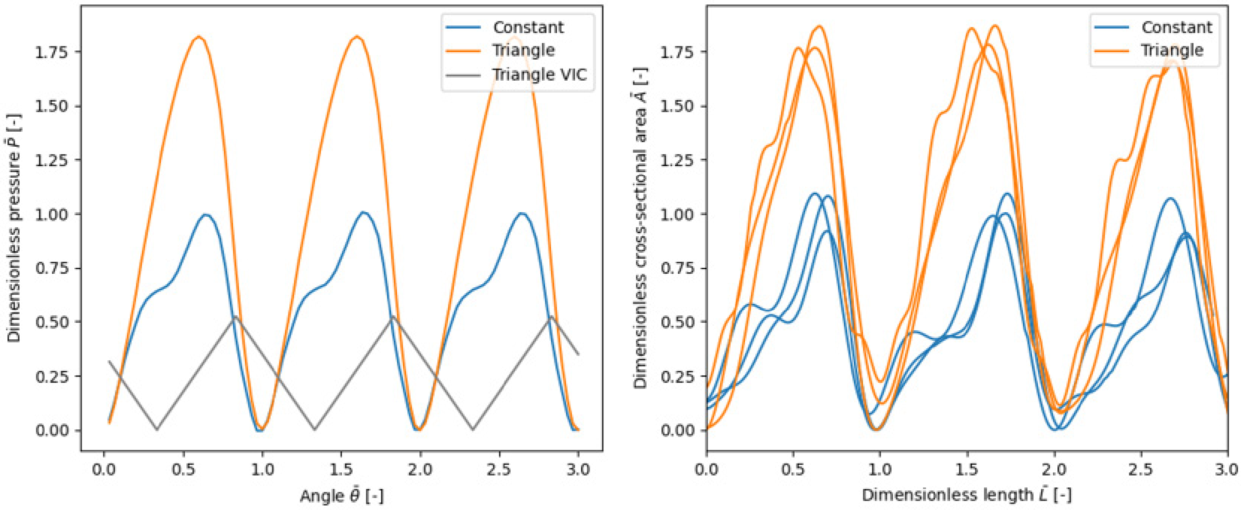

Figure 6 Comparison of the CFD simulation data with experimental data for a triangle shaped velocity input curve