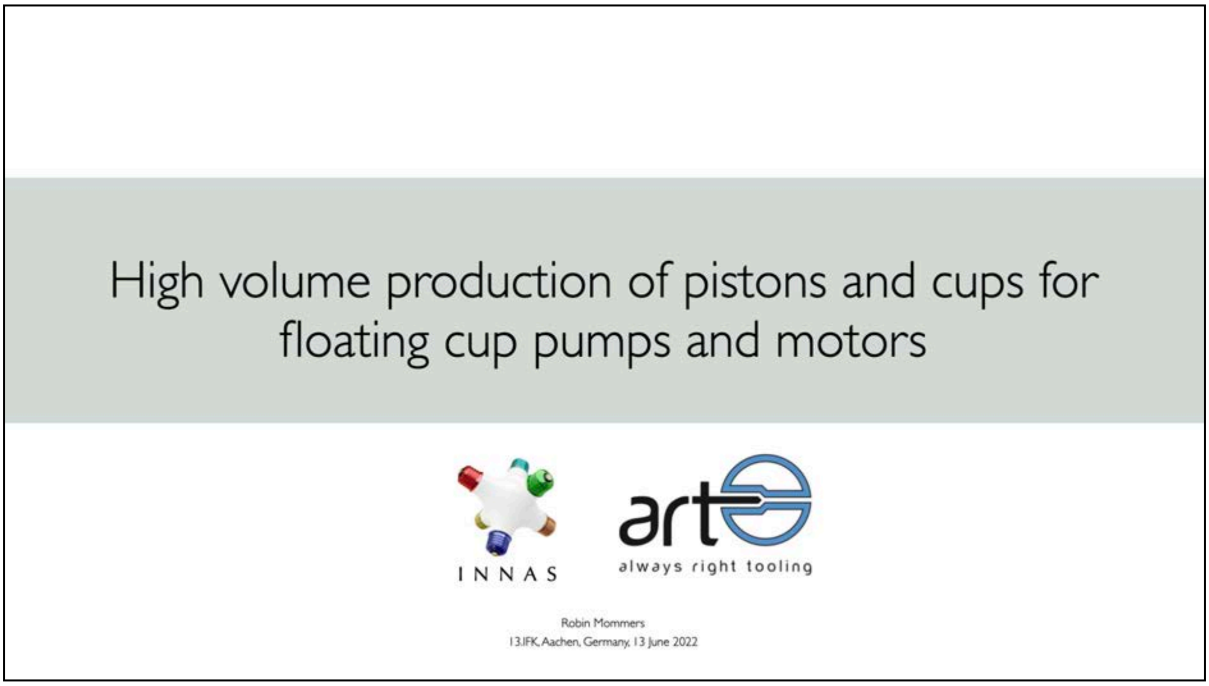
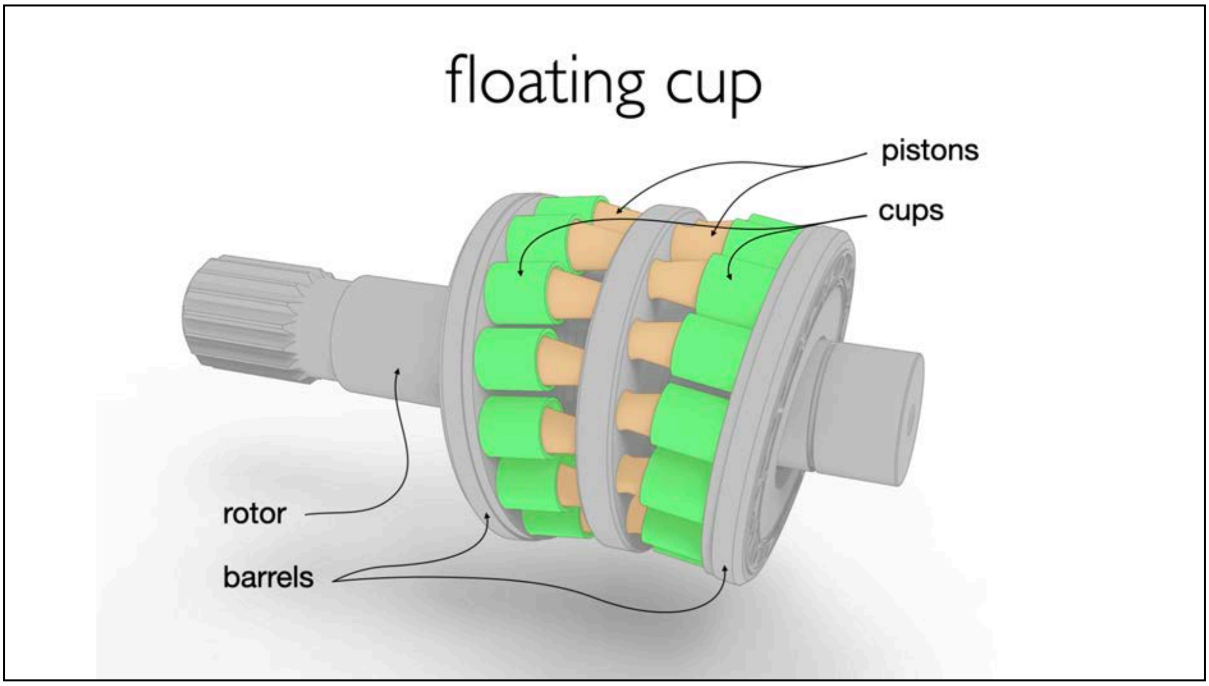


Presentation of Robin Mommers about using a novel production method to produce pistons and cups for a floating cup type pump or motor.

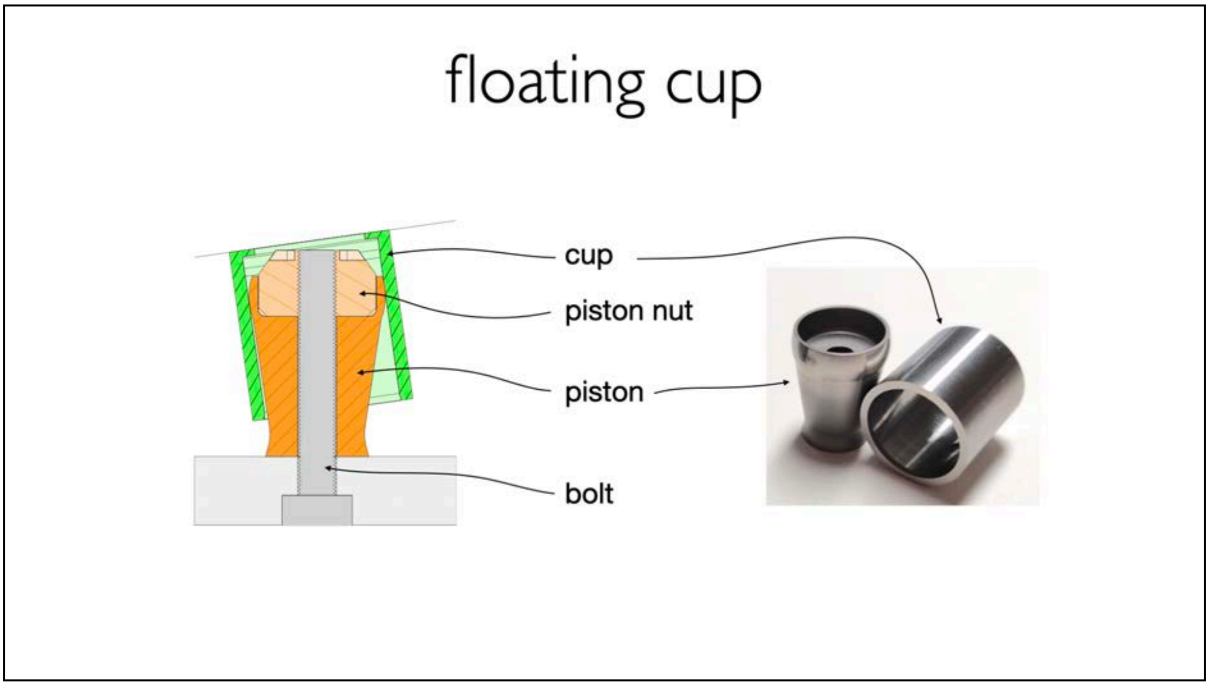
It will normally take an experienced machine operator a few minutes to produce a single piston for a hydrostatic pump or motor. Since these components require relatively strict tolerances, and you need multiple pistons to make a full pump, the production time for a single piston will have a large influence on the total production cost of such machines.

In a collaboration between Innas and ART group, we have investigated a way to drastically reduce the production time, at least for pistons for floating cup type machines. The result is a production process that can potentially produce a piston, as well as a cup, every single second. This process not only greatly reduces production costs, but also offers a way to easily up-scale the production.



For those of you who might not be very familiar with floating cup technology, let’s have a look at the components we will be talking about. This figure shows the rotating parts of a typical pump.

The rotor runs from left to right in this figure, and is the main axle of the machine. The middle of the rotor consists of a solid disk, on which the pistons are fixed in both directions. In this case, there are 28 pistons. Each piston has a cylinder, or cup, that is supported by a barrel on both sides of this disk.

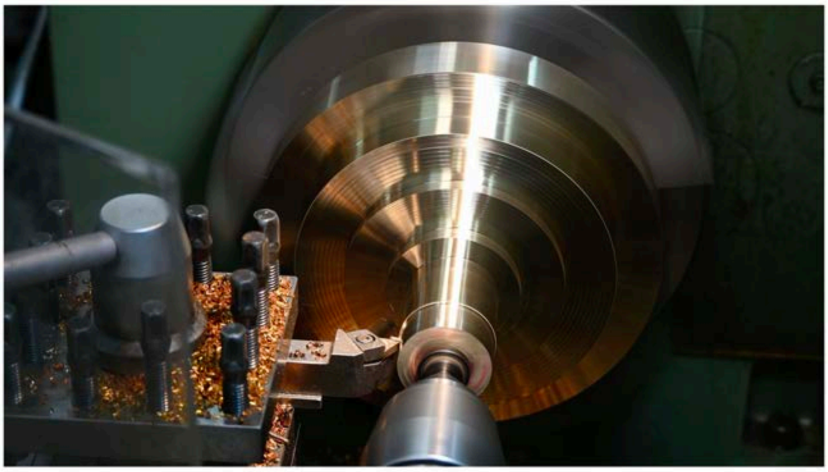


Looking at a cross-section of the piston and cup shows that the piston is fixed to the rotor by means of a bolt. The position of the cup is determined by the position of the piston, but it can move freely along the plane that supports it.

A picture of the actual components clearly shows that the head of the piston has a spherical shape. This is why it is possible for the cup find follow the piston during the rotation of the rotor.

Looking more closely at the picture of the actual components also shows traces that indicate how these components were made.

traditional manufacturing



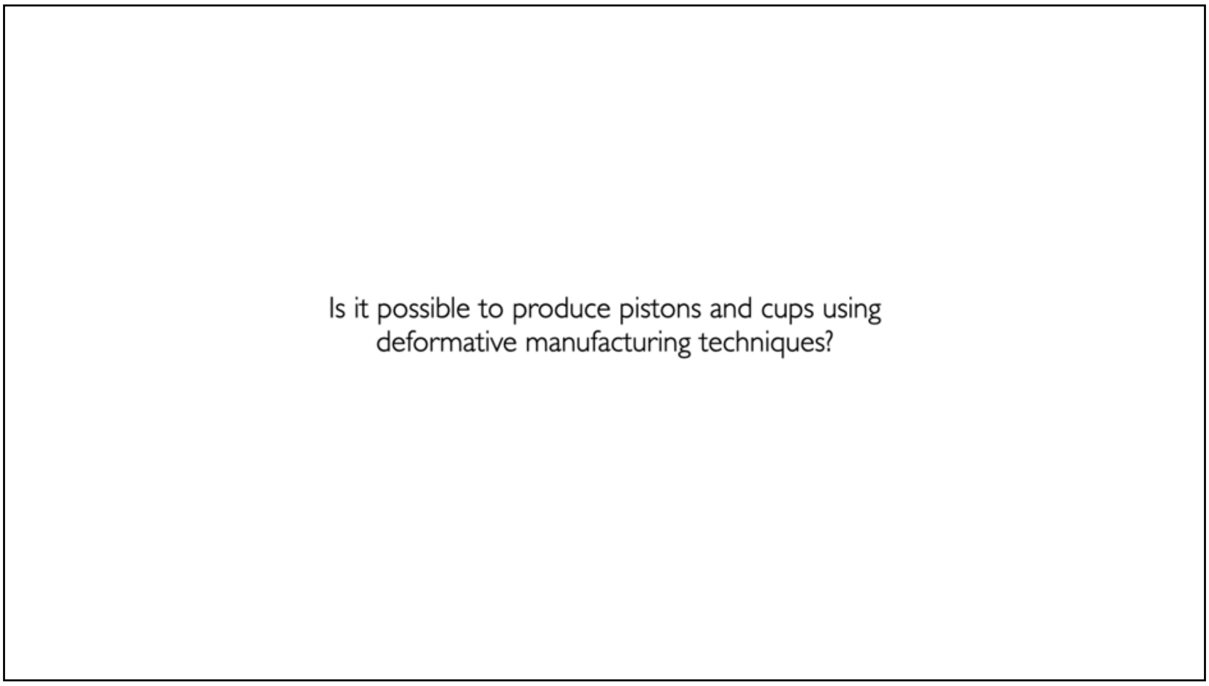
Traditionally, components are manufactured using tools like a lathe or a mill. In these cases, you start off with a piece of material that is larger than your end product. Using the mentioned tools, material is removed until the components is completed.

For this study, we looked at a different manufacturing technique. This technique is not based on removing material, but on deforming it.

deformative manufacturing

When using deformative manufacturing techniques, you start off with a piece of material that has a completely different shape than your end product. In this example, you see a machine called a press, and you can see a strip of metal moving into the press from the right. Each tool on the press represents a step of the production process. During production, the top half punches down on the metal strip, and deforms the material between the tool and the rest of the machine. Once the press moves up again, the material is moved to the next tool. At the final tool, the product is completed, and leaves the machine.

Since all of these production steps occur in parallel, each punch of the press results in a finished product. In other words, this is a fully automated, very fast production process.



And this leads us to the main research question of our study: Is it possible to produce pistons and cups using deformative manufacturing techniques?

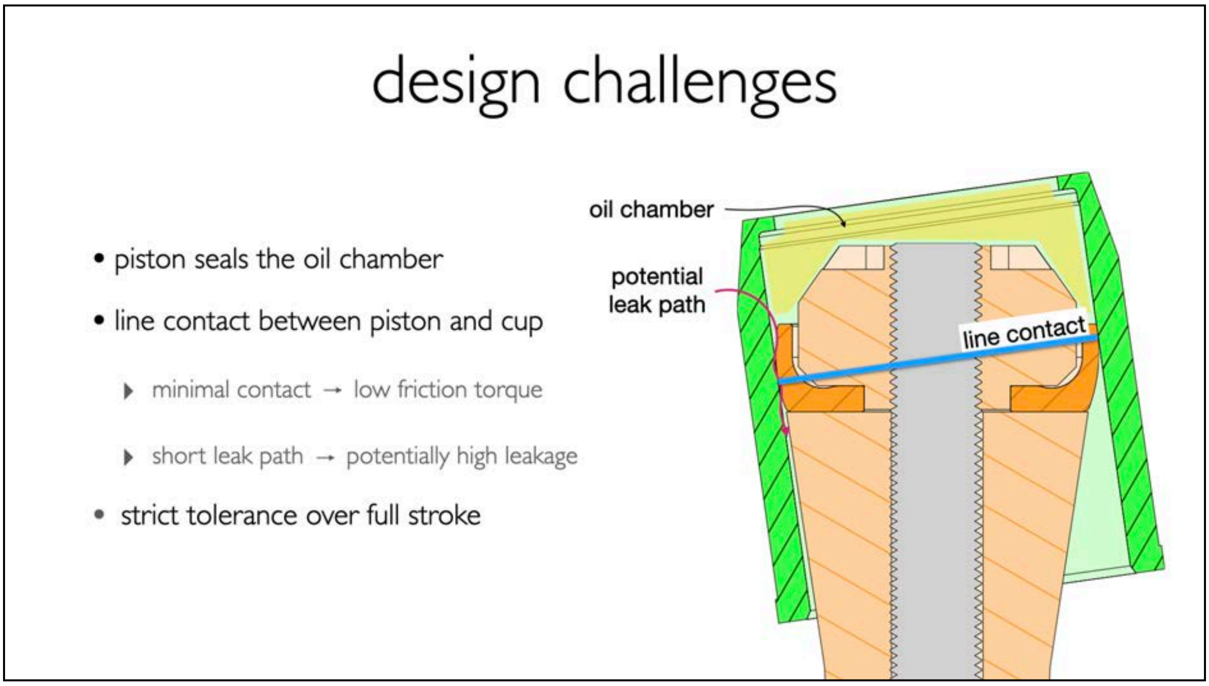
design challenges

Before we can answer this question, there are some challenge to overcome with regards to the design of our components.

As you can probably imagine, it is much easier to deform a piece of sheet metal, than it is to deform a big chunk of steel. This is why we need relatively thin products for a deformative manufacturing process.

Since the original piston design does not consist of thin material, this component was split into two parts: 1) a relatively simple pillar, and 2) a thin walled piston crown. This last part will be made using deformative manufacturing.

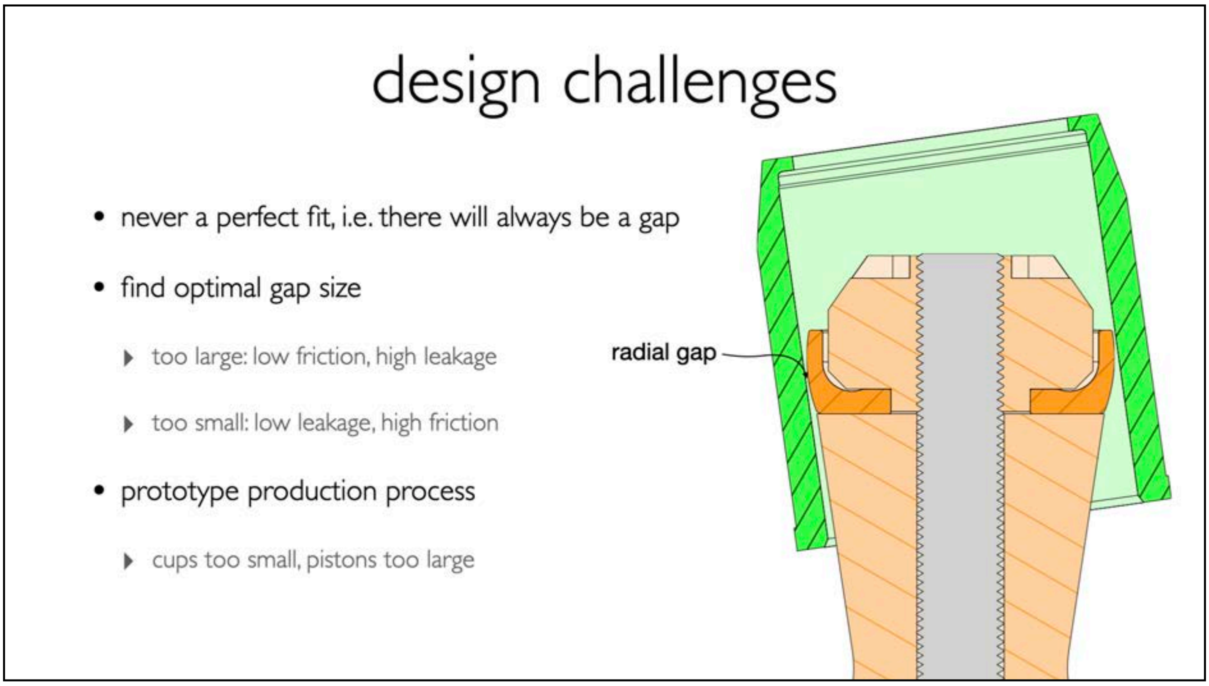
The spherical shape of the original piston is now found on the crown.



This spherical shape is very important for pumps and motors of the floating cup type. The main function of the piston is to seal the oil chamber. In the orientation shown here, there is oil in front of the piston.

Since the piston has a spherical shape, and the cup is a cylinder, there is a line contact between these two components. As a result of this line contact, there is very little friction between such pistons and cups, which is one of the reasons why a floating cup type pump has very little torque losses. On the other hand, this line contact also means that there is a very short leak path for oil to leak out of the oil chamber. This can potentially result in high leakage losses.

To ensure a good line contact, the tolerances of both the pistons and cups are very strict.



When we talk about tolerances, we have to think about what it means to manufacture two components that have to fit together. In the real world, these two components will never fit together perfectly. In this case, there will thus be a gap in the radial direction.

An important part of the current study has been to determine the optimal gap size for this application. From the previous slide, it can be concluded that a gap size that is too large will result in very little friction loss, but high leakage losses, and vice versa. In theory, there should be an optimal gap size somewhere in the middle.

To find this optimal gap size, we have opted for a prototype production process, in which we intentionally made the cups too small and the pistons too large (i.e. they will not fit together). By machining these components to different specifications in post-process, we can test and compare the performance of different gap sizes.

design challenges

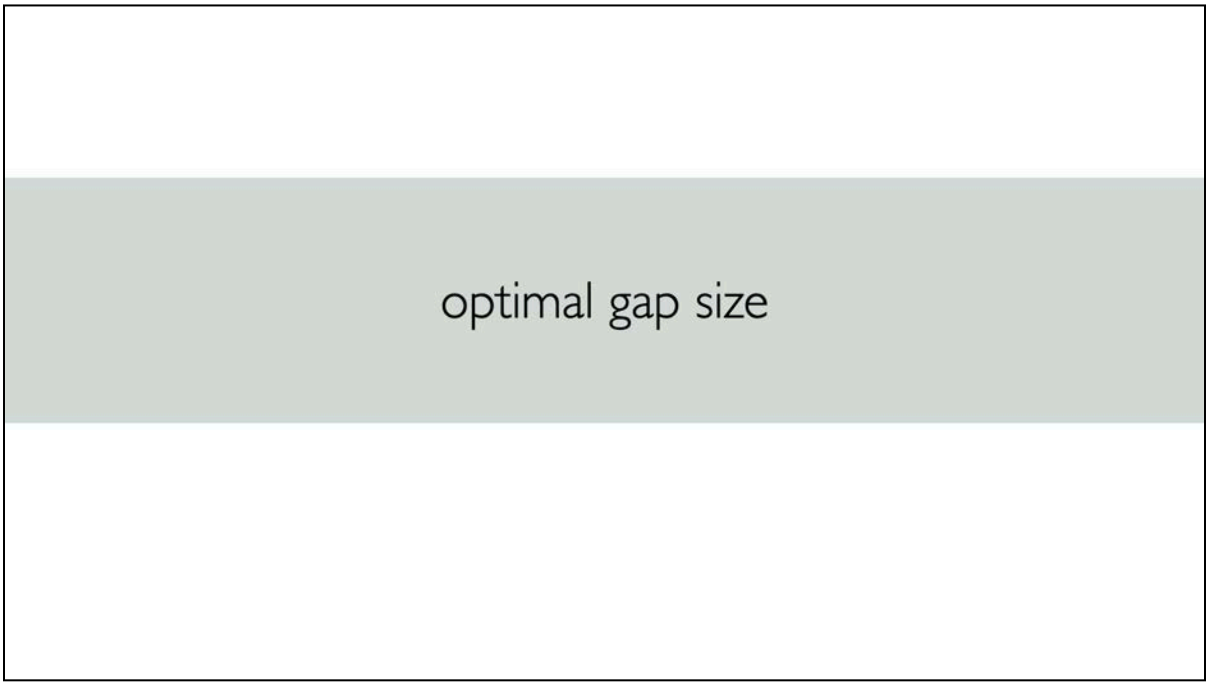
- cup process of 11 phases

- piston process of 6 phases

- prediction: final production process can potentially
  - produce 60 products per minute (or more)
  - need little to no post-process machining

ART group has designed the prototype production process for both the pistons and cups. The pictures show the products between the different production steps.

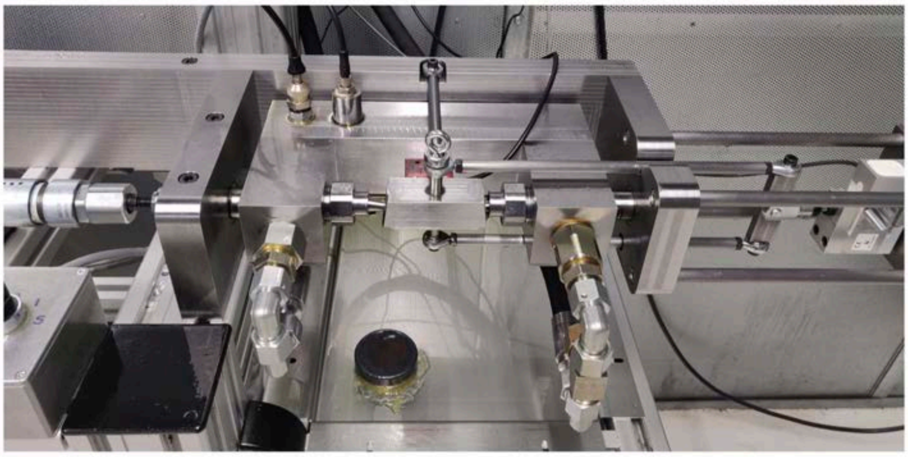
From their years of experience, ART group has predicted that a final production process that is based on this prototype process has the potential to output at least 60 products per minute. These products will then probably need little to no post-process machining.



For now however, we are working with the products from the prototype production process.

So how do you find the optimal gap size for these products?

optimal gap size



We have performed several measurements on this test bench that was designed specifically for this purpose. This device can measure the friction and leak flow rate between a single piston and cup.

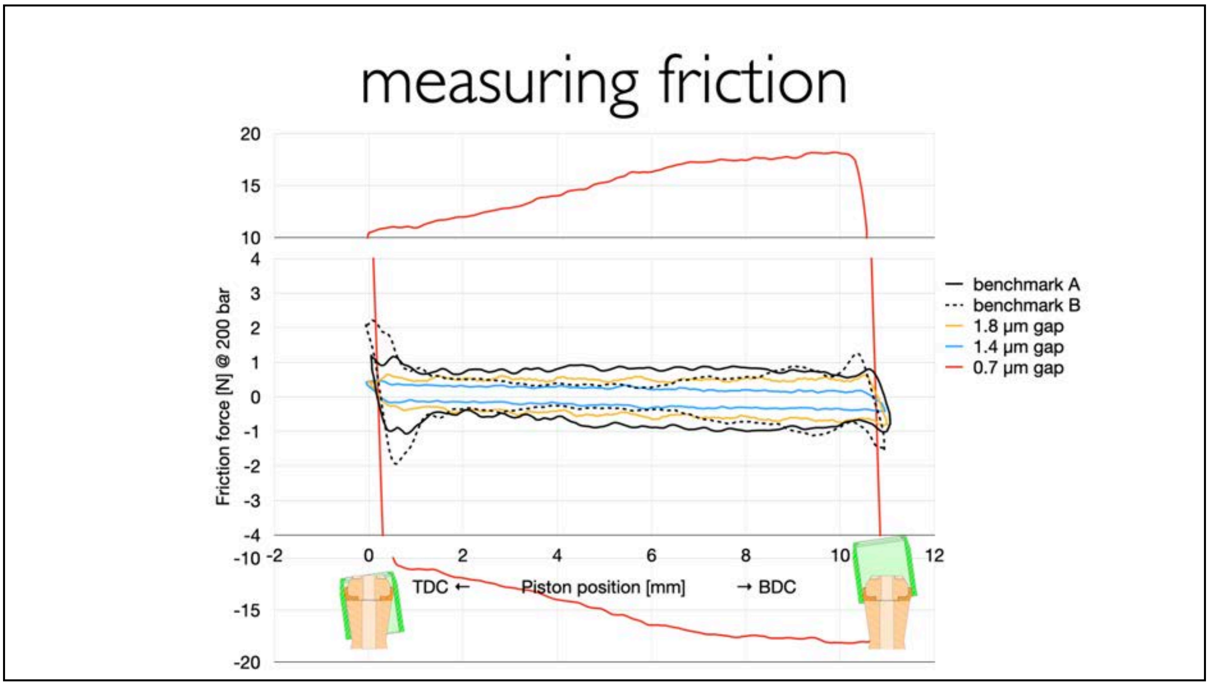
More details on how this machine works can be found in the paper. For now, we will only focus on some of the results that we found.

optimal gap size

- results presented today
  - friction and leak flow rate at oil pressure 200 bar
  - average radial gaps 0.7 μm, 1.4 μm, 1.8 μm
  - compare to traditional components (benchmark)

Today we will only look at the measured friction and leak flow rate that were measured at an oil pressure of 200 bar.

We will compare the results of three combinations of pistons and cups with different gap sizes that were made using the new production process, as well as two combinations of pistons and cups that were made using the traditional production method. Since we know that these traditional components work well in the actual pump, these measurements will function as a benchmark to compare the new components to.

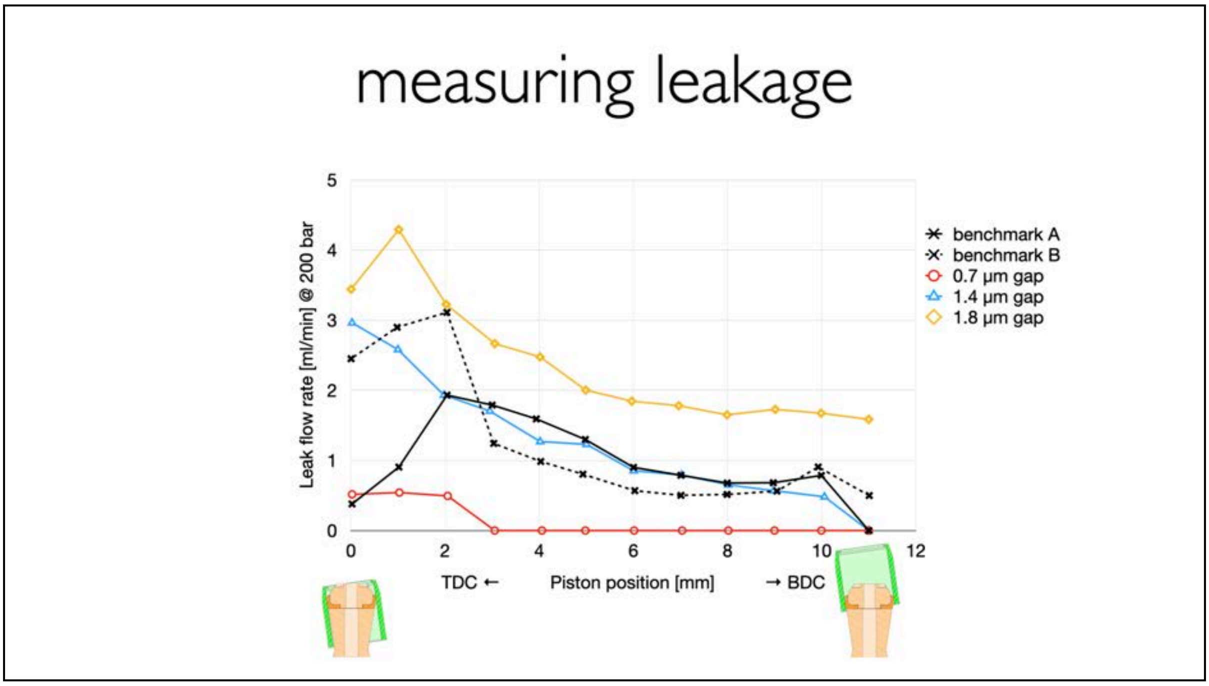


This graph shows the measured friction force between a single piston and cups on the vertical axes. The horizontal axes shows the position of the piston inside of the cup, as it moved back and forth. For some perspective on the amount of friction: an oil pressure of 200 bar corresponds to a piston force of 3 kN for these pistons.

The two benchmark measurements show that the friction was less than 1 N for the most part of the piston stroke. Only near the top dead centre (TDC) and bottom dead centre (BDC), this friction increased to a maximum of 2 N.

The pistons and cups with a radial gap of 1.8 and 1.4 µm performed roughly the same as the two benchmarks. Interestingly, these components did not show a significant increase in friction near the TDC and BDC positions. This is likely caused by the new designs.

The piston and cup with a radial gap of 0.7 µm shows much more friction, which the measurement almost reaching 20 N. This simply means that such a radial gap is too small.

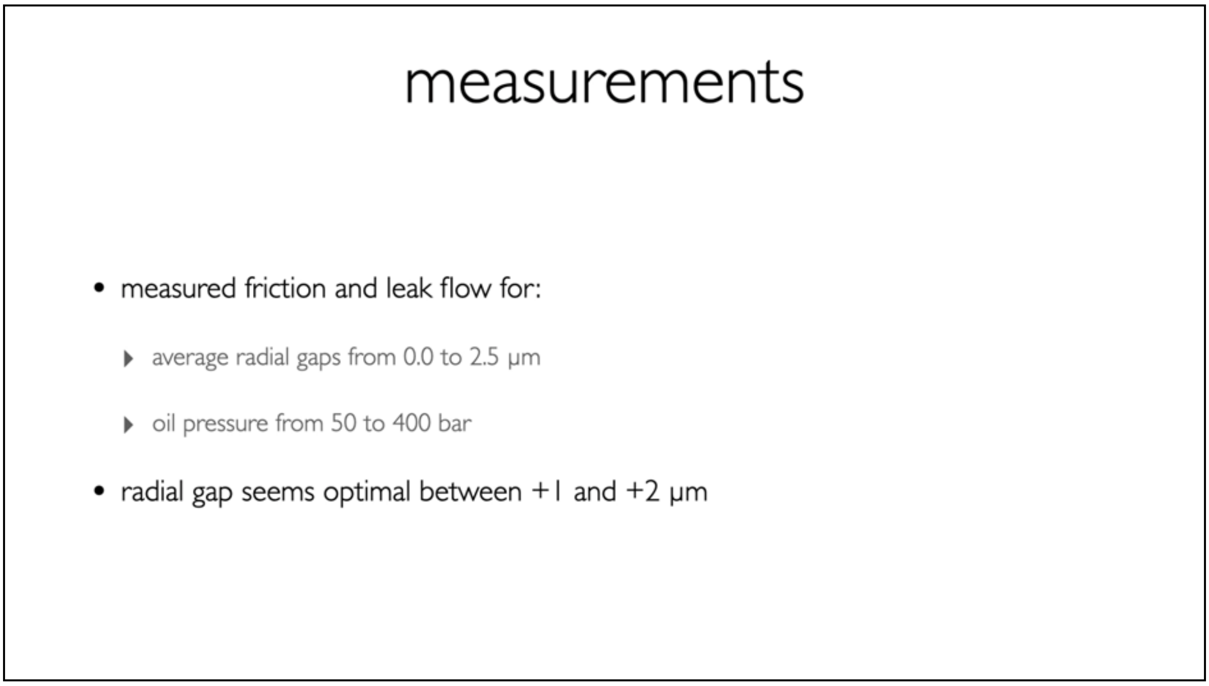


Similar to the friction losses, this graph shows the measured leak flow rate with the piston at different positions inside of the cup.

The two benchmark measurements show similar leakage patterns. Starting from the right side of the figure, the leak flow rate increases as the piston moves towards TDC. However, in the position closest to TDC, the leakage start to decrease again. This correlates to the increase in friction we saw in the previous slides.

Looking at the results of the components with a radial gap of 0.7 µm, it is found that there was almost no leak flow between these two components. This also correlates to the friction measurements: high friction <-> low leakage.

The pistons and cups with a radial gap of 1.8 and 1.4 µm again performed roughly the same as the two benchmarks.

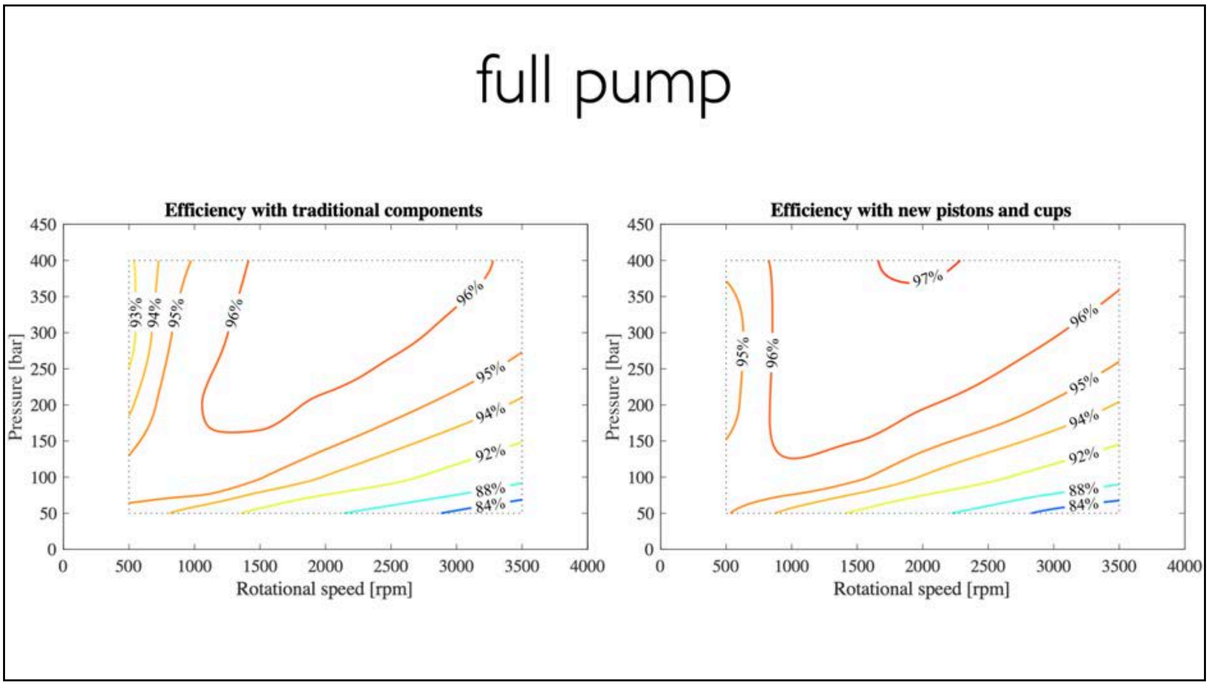


For this study, we have performed many more such measurements. We measured components with radial gap sizes ranging from 0.0 to 2.5 μm, at oil pressures ranging from 50 to 400 bar.

From all of these measurements, it was concluded that the gap size is optimal, somewhere between 1.0 and 2.0 μm.

full pump

With this knowledge, we made a larger batch of pistons and cups with a radial gap between 1 and 2 µm. We then measured the performance of these components in an actual floating cup pump.

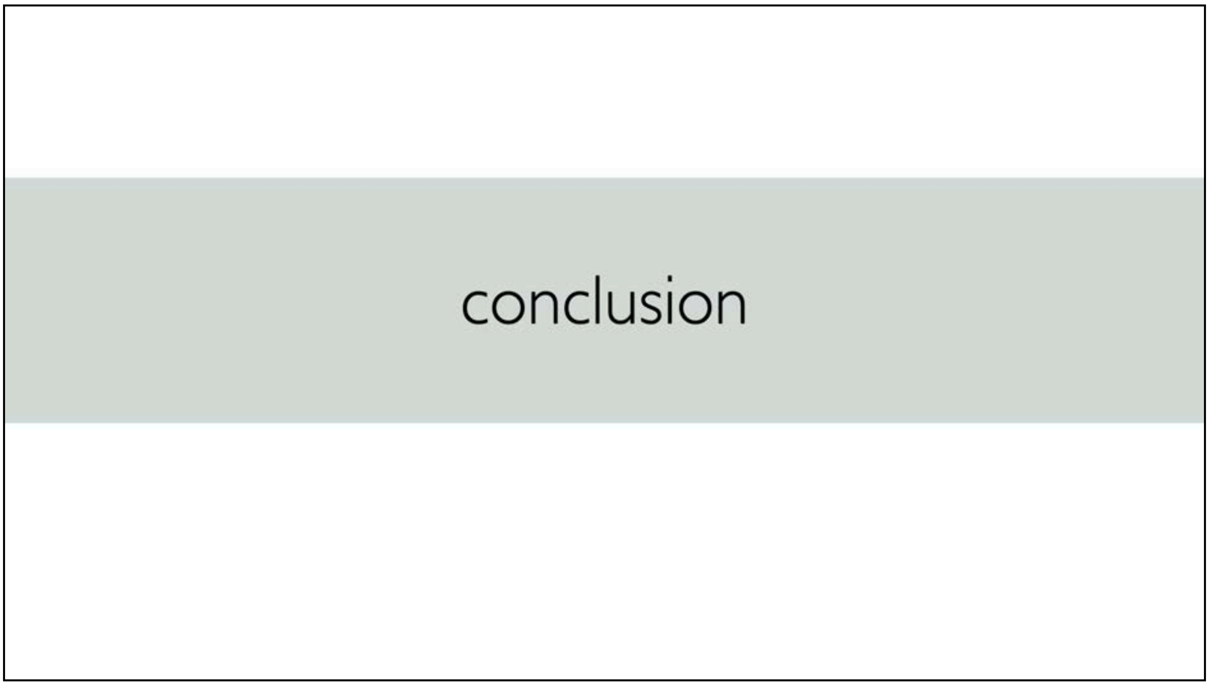


We first performed measurements on a prototype 45cc/rev floating cup type pump that had traditionally manufactured pistons and cups. We measured the efficiency of this unit at operating speeds ranging from 500 to 3500 rpm, at pressure levels ranging from 50 to 400 bar.

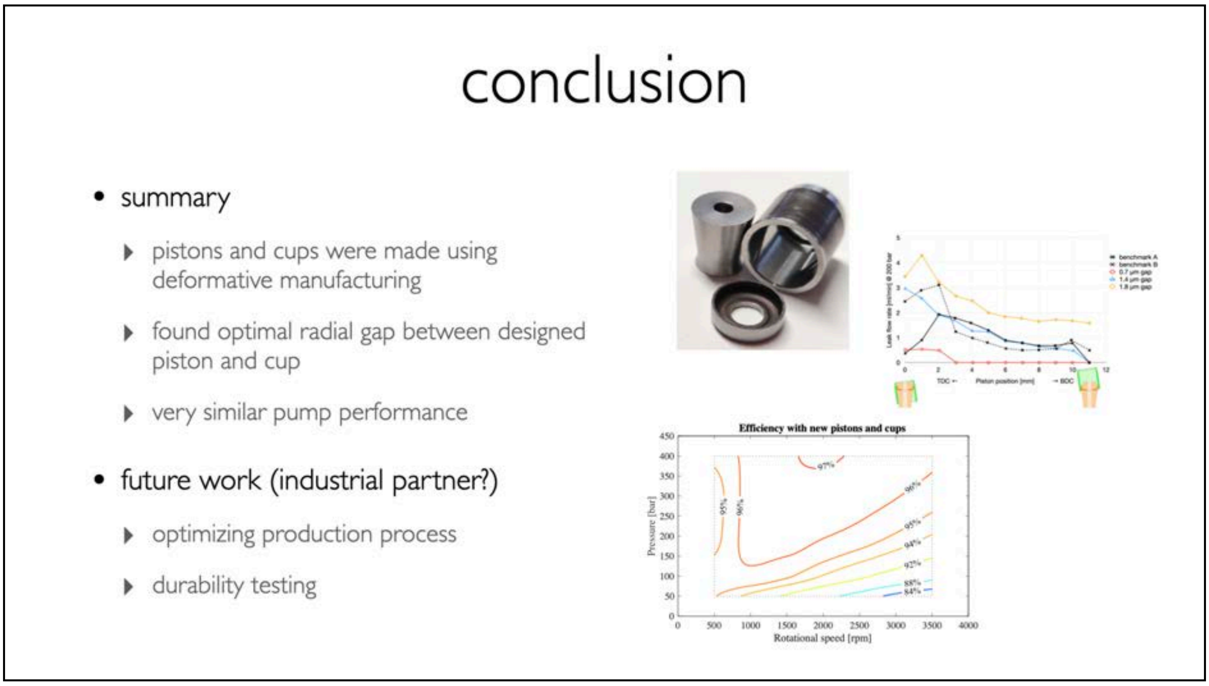
After this measurement was complete, we took the pump apart. We then replaced the pistons and cups with the new pistons and cups, and left all the other components as they were. After putting the machine back together, the measurement was repeated.

Looking at the results, we find that the performance of these two machines was very similar. The efficiency of the pump with the new pistons and cups was even slightly higher at some operating conditions. These slightly higher efficiencies could be within the margin of error.

The main takeaway from these results, is that there is no decrease in performance when using the new products, i.e. the new production process can produce pistons and cups that perform similar to the original components.



And this brings us to our conclusion.



In summary, we have made pistons and cups using a novel deformative manufacturing process. These components were first tested individually in terms of friction and leak flow rates. From these measurements, we found that there is an optimal radial gap between the piston and cup. Upon comparing the performance of a pump with traditionally manufactured pistons and cups to a pump with these new pistons and cups, we found no decrease in performance.

From our results we can conclude that, yes, it does seem possible to manufacture pistons and cups using such a deformative manufacturing process. However, this work has been a proof of concept, and there is still more work to be done. The production process needs to be further optimised in order to reach the full potential of this method. Additionally, we have not done any real durability tests. It will be important that these pistons and cups still work after thousands of hours.

These next steps will need to be taken in collaboration with an industrial that is willing to challenge the current status quo of manufacturing, and actually bring this exciting technology to market.

And with this conclusion in mind, I would like to give you a moment to think about how much pistons and cups we could have made during the time that you were listening to this presentation.

Please feel free to contact us if you have any questions.