ROB VAN MALSEN

FLOATING SENSATION

Developed after a chance discovery, the floating-cup design is a displacement principle that meets the toughest challenges faced by axial-displacement units. It looks set to be a massive success

Serendipity is the knack of finding things you were not looking for. Aptly, in its search for the ideal hydraulic transformer, Innas – a hydraulics R&D company based in Breda, The Netherlands – developed a new displacement principle for hydraulic machines.

The floating-cup design has not only generated a low-cost, high-performance solution for hydraulic transformers, but has also materialized into an ideal principle for hydraulic pumps and motors.

The floating-cup principle combines the advantages of the well-known and mature bent-axis and slipper-type units, and is medicine for the toughest problems of conventional axial-displacement units, such as reducing sound output, pulsations and costs.

Preliminary analysis conducted by IFAS in Aachen on the floating-cup pump confirmed the technical potential of the technology, while automotive production technologies such as deep drawing, fine blanking and stamping ensure the low cost of the principle.

Lean production

To realise an opportunity in the market, a new pump principle should be both technically superior and more economical to produce. With this in mind, Innas started looking at production technologies which enabled the automotive industry to produce numerous parts at an extremely low cost level. Components such as bearings and roller clutches are produced with accuracies within 1μm – non-cutting shape and smart classification technologies make it possible to produce them at very low cost. Such parts require the same high accuracy – and are also exposed to comparable heavy-load conditions – as those parts within hydraulic pumps. These components are all made by deep drawing, fine blanking and stamping.

Such has been the evolution of these technologies that low costs and high accuracy now run side-by-side.

Fully automated classification makes it possible to match the parts up to the required accuracy of just 1μm. Using

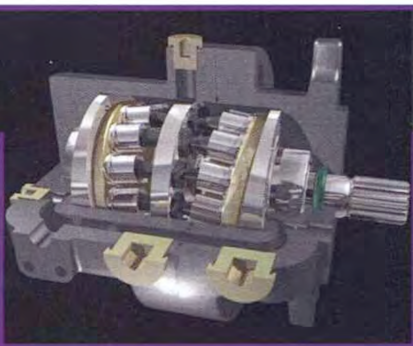

FIGURE 1: **Cutaway view of the first prototype of a floating-cup pump**

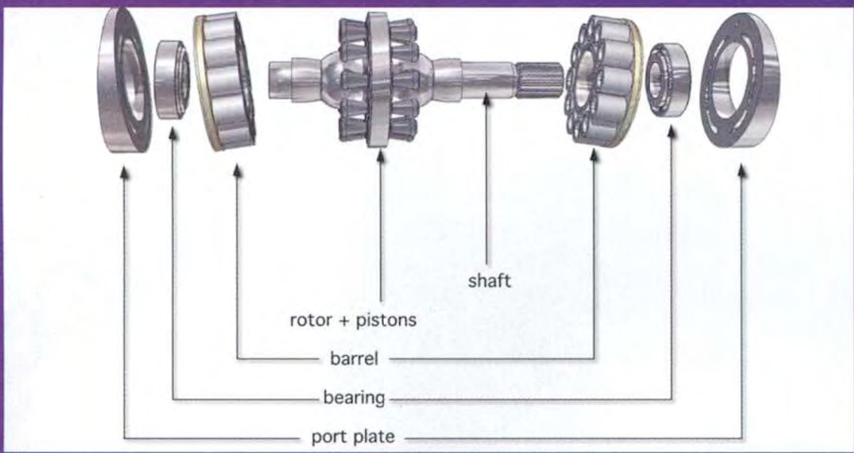

FIGURE 2: **Main parts of the rotating group of the floating cup pump**

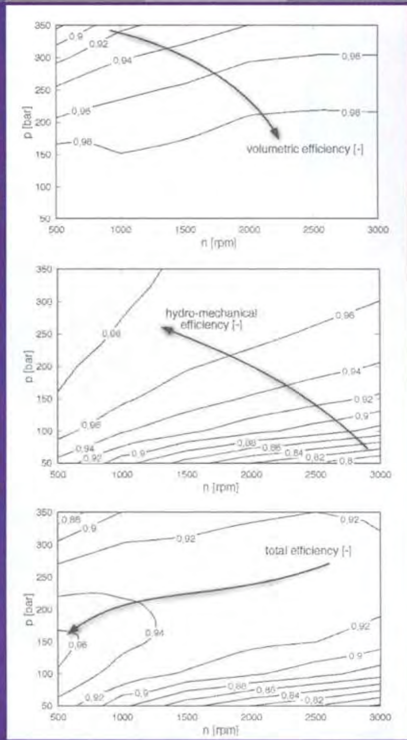

FIGURE 4: **Showing floating-cup efficiency**

these technologies for the production of conventional piston pumps, however, does not make any sense: classification of a conventional barrel with seven or nine holes all with different sizes is impossible. In addition, conventional hydraulic pumps are filled with stacked chains of tolerances, and can only be produced with conventional machining technologies including milling, drilling and grinding.

Possibilities to further decrease the costs of these conventional slipper-type and bent-axis pumps are drying up, although a wealth of modern production opportunities do exist and are waiting in the wings before flooding the hydraulics industry. It was in an attempt to enforce a breakthrough in this area that led to Innas unveiling its floating-cup principle in March 2002, combining technical advantages with lean production methods.

Simple design

In order to prove the potential of the design, Innas designed a $28cm^3$ pump with 24 pistons, which can cope with a maximum pressure rating of up to 400 bar and a maximum rotational speed of approximately 5,000rpm.

Figures 1 and 2 show the floating-cup pump design. Most striking is the mirrored design of the new concept. Unlike other axial-piston pumps, the pistons are rigidly connected to the rotor which is then fixed onto the shaft. Each piston has its own separate cylinder and a rotating disc supports these cylinders or cups. This so-called barrel plate allows the commutation of the cylinders between the low- and high-pressure ports in the port plates – the shaft also drives the barrel plates (Figure 3).

Two pivots in ball-shaped extensions on the shaft synchronise the movement of the barrel plates with the shaft. The load on this universal joint is very low; only the friction forces between the barrel and the port plate and some inertia forces have to be taken by the joint. Unlike in-line pumps and motors, there is no hydraulic power transmitted through the barrel or the joint between the barrel and the shaft.

Pumping principle

The pump's displacement is realized by positioning the port plates at an inclined angle relative to the rotary plane of the pistons. Due to the angle between the barrel and rotor, the projected circular movement of the pistons and cylinders will be slightly elliptic on the inclined plane of the barrel plate. In addition, the deviation between the circle and the ellipse is taken by the cup-like cylinders, floating on the barrel plane.

These floating cups are hydraulically balanced on the barrel. Specific dimensions are chosen so that the cups are pushed onto the barrel plane slightly when being pressurized. During the suction stroke, hydraulic pressure will in most cases be insufficient to hold the cups against the barrel plate, so holding plugs keep the cups in position.

The prototype has 12 double-sided pistons, though the pump can easily perform as a 24-piston pump by shifting the top dead centres of the port plates.

Combining benefits

Although the number of components has increased compared with bent-axis and slipper-type pumps, the production costs of floating-cup machines are significantly lower. Analyzing this more carefully, it can be seen that the floating-cup design breaks with expensive chains of tolerances and that all parts can be produced with automotive production technology.

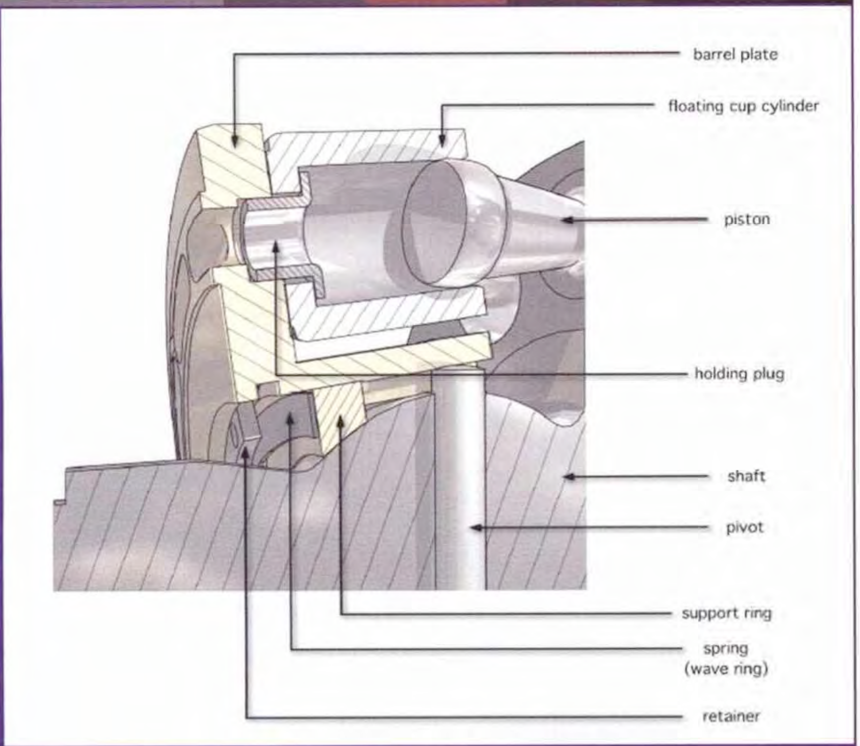

FIGURE 3: **Detailed cross-section of the barrel assembly**

The floating-cup machine combines the advantages from the slipper-type and bent-axis principle and features the high efficiency of a bent-axis unit, but also offers the throughdrive of an in-line machine. Apart from this, the floating-cup unit has additional advantages directly related to the design.

Of great importance for the hydraulics market is the reduction of noise, whether it is structure borne or fluid borne. Structure-borne noise from the floating-cup units is decreased due to a balanced construction, which reduces the load on the bearings. The high number of displacement volumes also reduces structure-borne and fluid-borne noise.

In addition, the high number of pistons reduces the pressure pulsations by up to 80% compared with conventional pumps, which also positively affects system leakage: reduced pulsations result in fewer sweating couplings and sealings. The strong reduction of pressure pulsations will also improve the controllability of systems when using a pressure feedback for advanced electro-hydraulic controls.

The high number of pistons applied in the floating-cup design also reduces the torque variations, which improves the start-up behaviour of hydraulic motors. Furthermore, the floating cup has a high hydromechanical efficiency, especially at start-up and low speed. This will improve the breakaway and low-speed characteristics of hydrostatic motors. Self-priming performance of the floating-cup pump is improved (compared with conventional piston pumps) due to the short piston stroke and large piston diameter.

A 28cm³ floating-cup pump

Total efficiency is already comparable to the efficiency of conventional bent-axis or swash-plate pumps.

Performance measurements

Preliminary efficiency tests performed by the Institut für Fluidtechnische Antriebe und Steuerungen (IFAS) of the University of Aachen show the volumetric, hydromechanical and total efficiency of the floating-cup pump. The volumetric efficiency is higher then 96% for the largest part of the measured field. This will be further improved by a better balance of the barrel plates, a smaller gap height between pistons and cups, and by creating a pressure-compensating cavity in the piston.

The hydromechanical efficiency, shown in the second diagram (Figure 4), is in the largest part higher than 94% due to low torque losses, low bearing load and low friction between cups and pistons. The third diagram (Figure 4) shows that in a large part, the total efficiency of the floating-cup pumps is higher than 92%, also when at maximum pump power. This means that the total efficiency for the prototype is already comparable with conventional axial-piston pumps. However, there is still room for further improvement of the total efficiency when the volumetric losses can be decreased.

Outlook

Floating-cup technology is expected to fill a gap in the development of more economical, quiet and altogether better-performing hydraulic systems.
Efficiency has already been proven to be comparable with conventional units while pressure pulsations are reduced by up to 80% compared with conventional pumps. In addition, motor behaviour is excellent and where the possibilities for further improvement of the bent-axis and swash-plate units are almost exhausted, the floating-cup principle offers new opportunities.

That said, a fundamental change in production technology will be decisive. Studying recent patterns within the hydraulics industry, it is clear that improvements to conventional designs are near an end, yet there is an emphasis on reducing production costs. The floating-cup design provides a breakthrough in this respect as it opens up the doors for mass-production technologies for hydraulic machines, while offering other chances for the hydraulics and the automotive industry. ***iVT***

Rob van Malsen has worked at Innas for 11 years. He is also program manager for Noax, the company responsible for licensing the technology developed by Innas