A Low-Flux Polyurethane Restrictor for High-Stiffness Hydrostatic Bearing Over a Wide Range of Loading

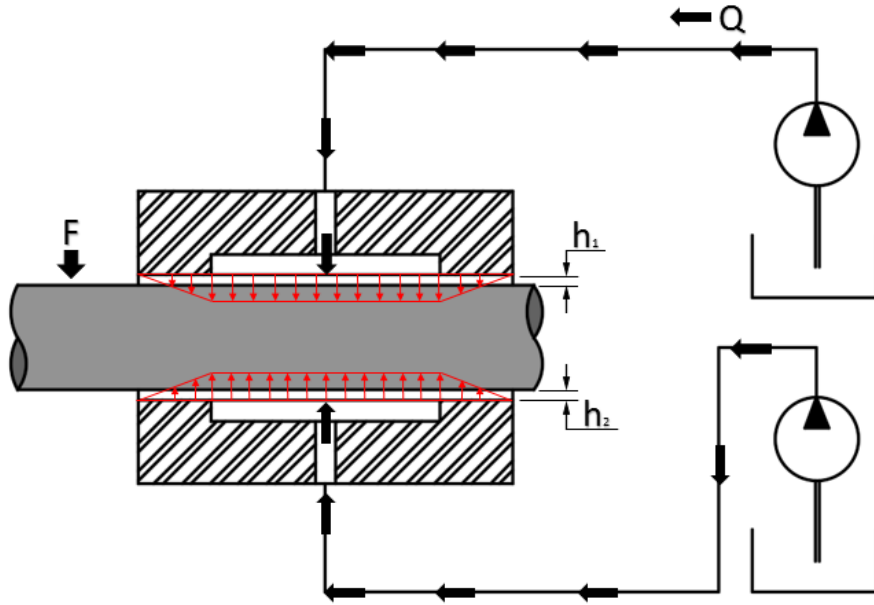SY-WEI LO[1], YOU-YI LIN[1], JYH-CHYANG RENN[1], TSUO-FEI MAO[2]

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NATIONAL YUNLIN UNIVERSITY OF SCIENCE & TECHNOLOGY, TAIWAN
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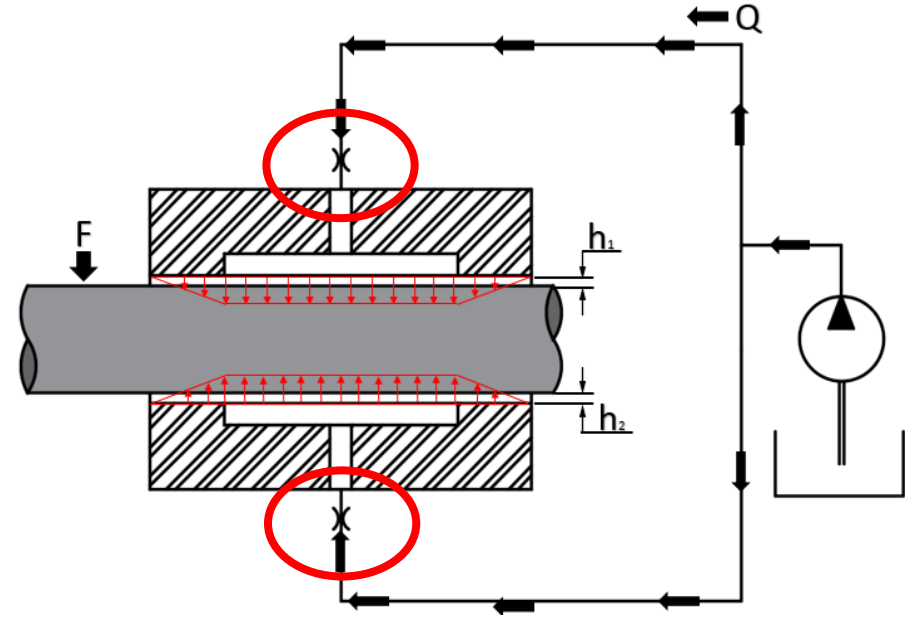CHIENKUO TECHNOLOGY UNIVERSITY, TAIWAN

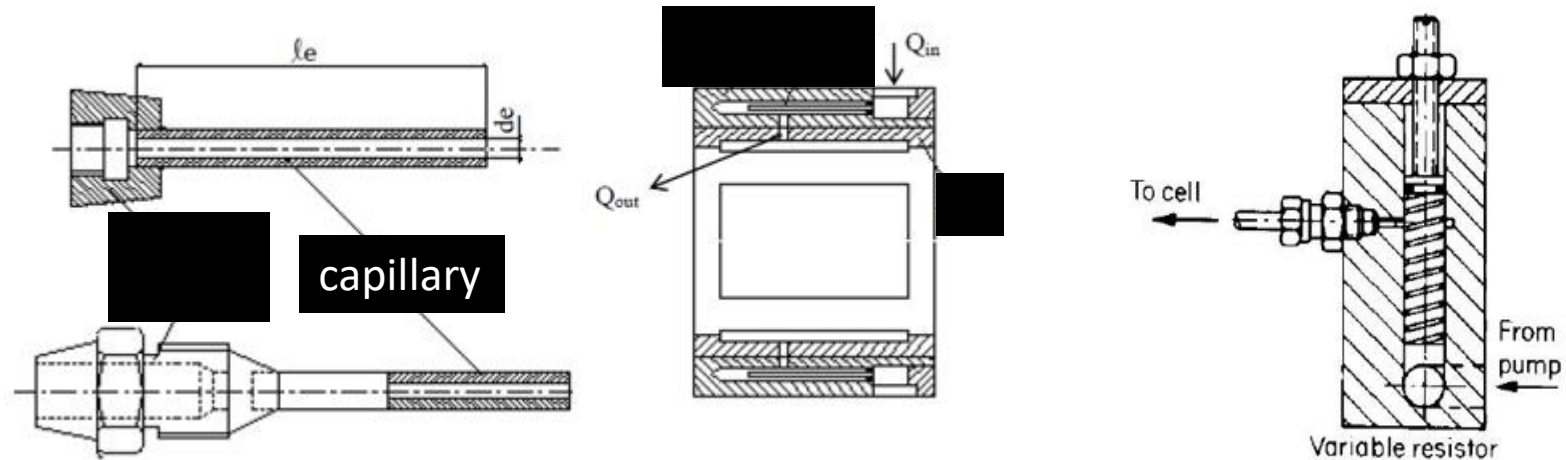#STLE2018 | @STLE_Tribology

System of Fluid Supply

Constant Flow Rate

Constant Pump Pressure

Pre-set Capillary Restrictor

The **length** of the capillary is pre-set and not changed during operation. The drop in fluid pressure is proportional to the length and is very sensitive to the **diameter** of the capillary.
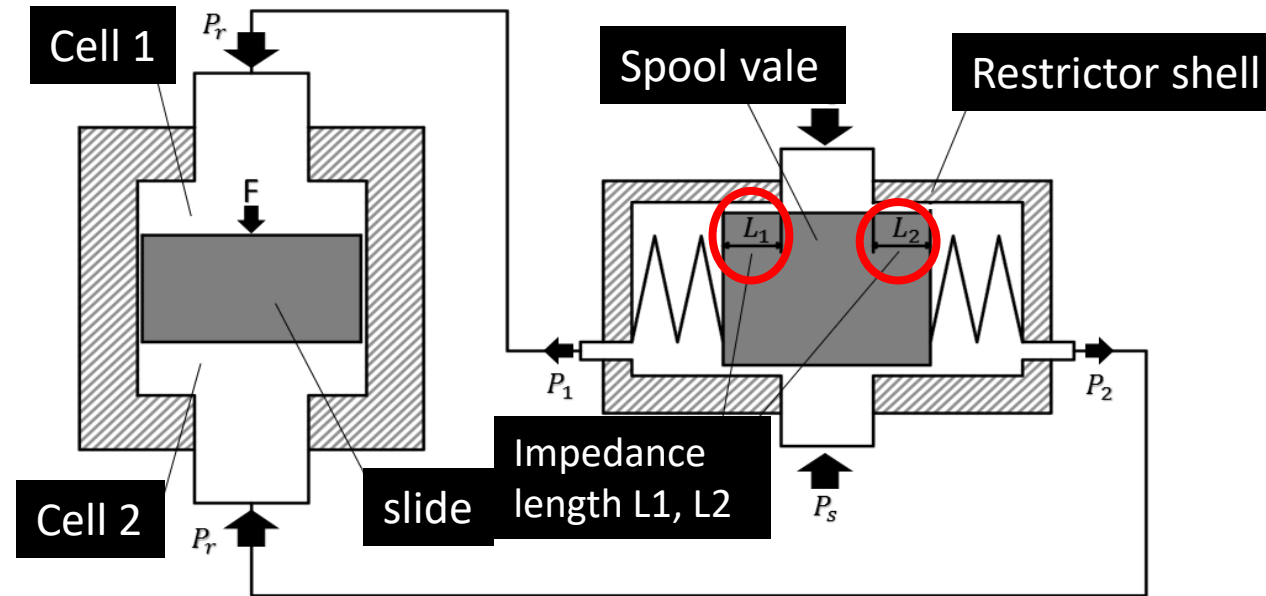

capillary

$$Q = \frac{\pi d_e^4 \Delta P}{128 \eta L_e}$$

$$R_c = \frac{128 \eta L_e}{\pi d_e^4}$$

Self-adjustable Restrictor: Spool Valve

The **position** of the spool inside the restrictor can alter according to the pressure difference in the opposite cells of the bearing. The impedances for the fluid to the opposite cells are therefore adjusted.
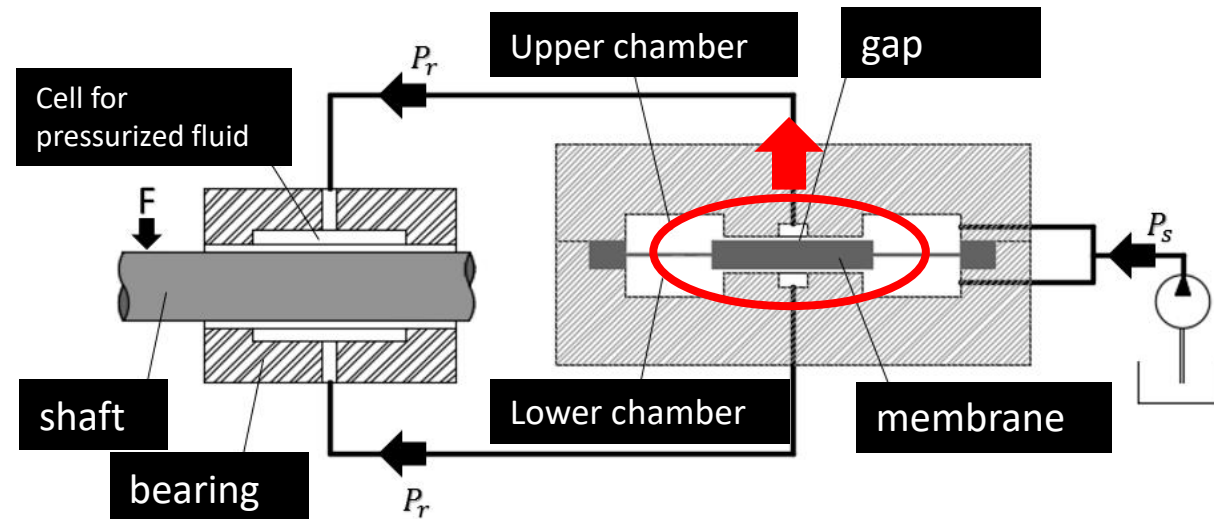
Self-adjustable Restrictor: Membrane Valve

The **gap** between metal membrane and the land is modified due to the cell pressure. It can be either single or dual directions for the movement of membrane. However, the requisite of the accuracy in fabrication and assembly is very demanding.
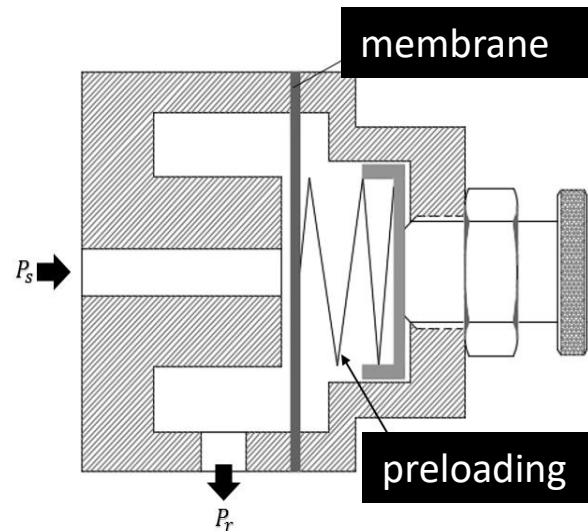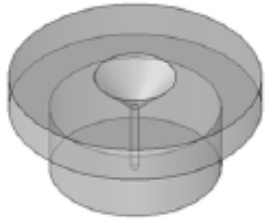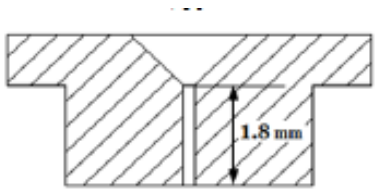

Single-direction movement

Dual-direction movement

New Restrictor: Deformable Polymer Capillary

The inlet of the capillary is widened by the supply pressure P_s and its outlet is narrowed due to the upward moving of the recess, pushed by the recess pressure P_r. The "nozzle" can generate higher load capacity with, however, much lower air consumption.

The flux of the air is only 1/10 to 1/3 of that of the conventional design.

Opened inlet

P_s Q

P_r
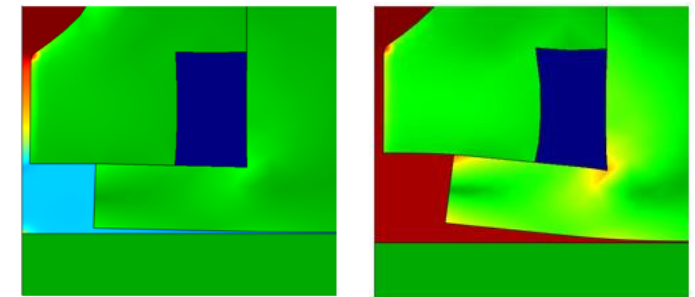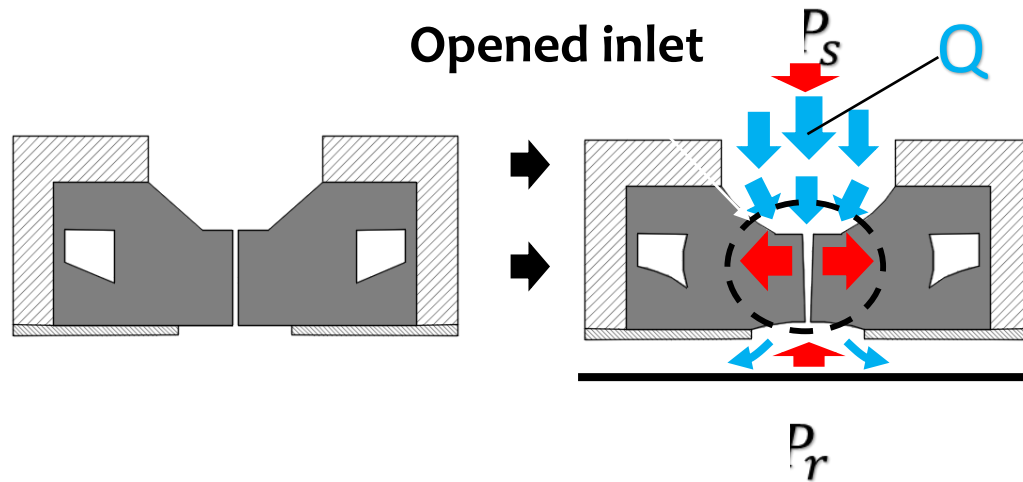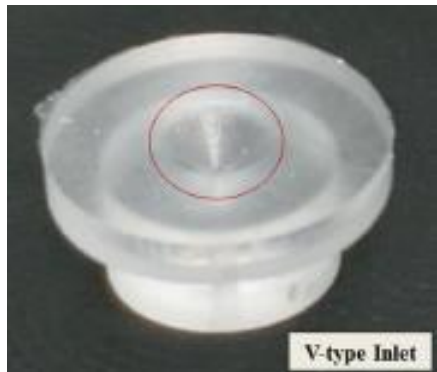
Deformation of Silicone Tube (Simulation)

First attempt: PU restrictor with single capillary
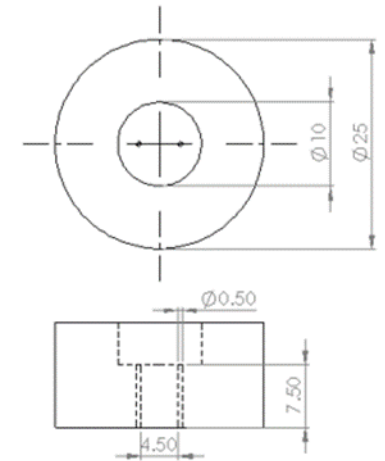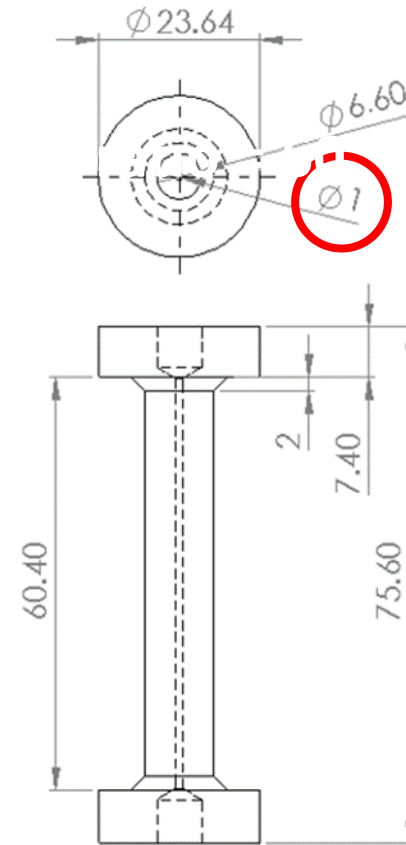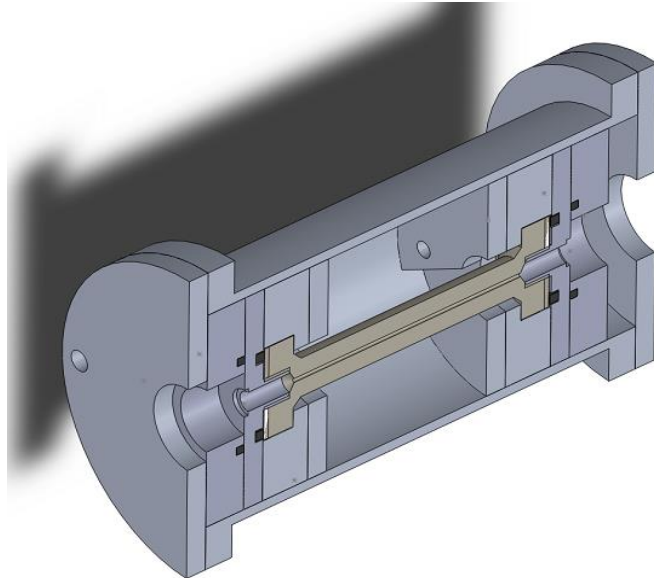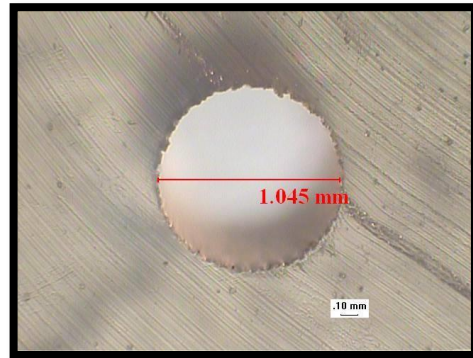
Refinement: PU restrictor with dual capillaries

$$R_c = \frac{128\eta L_e}{\pi d_e^4}$$

- To simplify the structure and reduce the difficulty in manufacture, the dual capillary design is adopted instead.
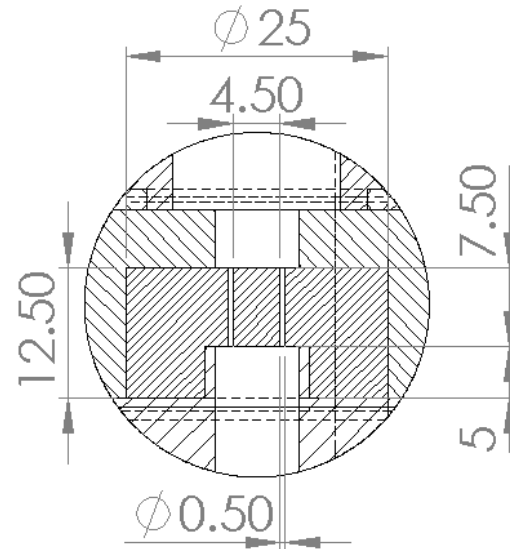- To match the impedance of the single-capillary design, the diameter d_e is reduced 50% (0.5 mm) and the length L_e becomes 1/8 (7.5 mm).

Dual PU Capillaries

Section A-A
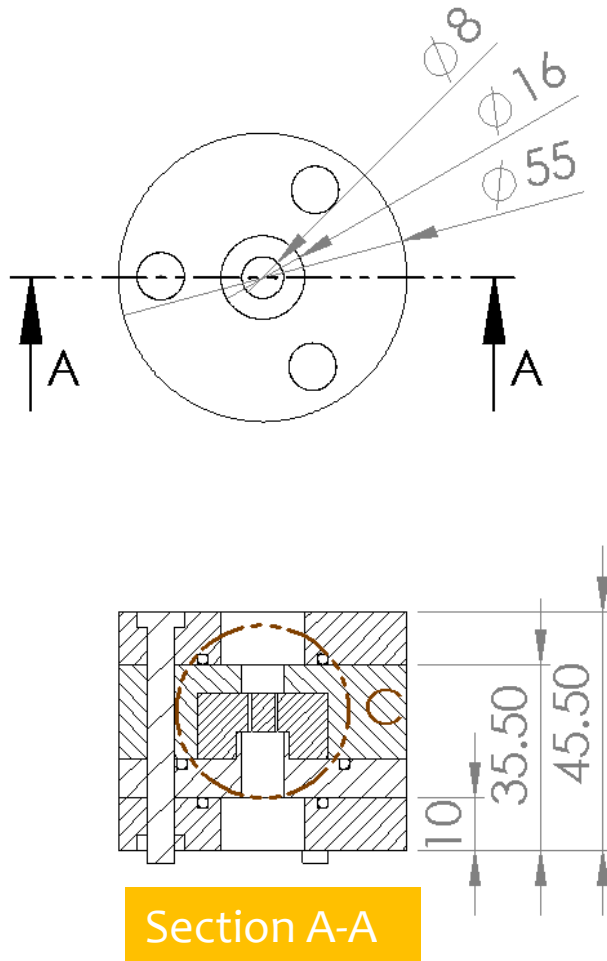
Enlarged details of C region

Dual AL Capillaries

Section A-A

P_s P_r

Enlarged details of B region
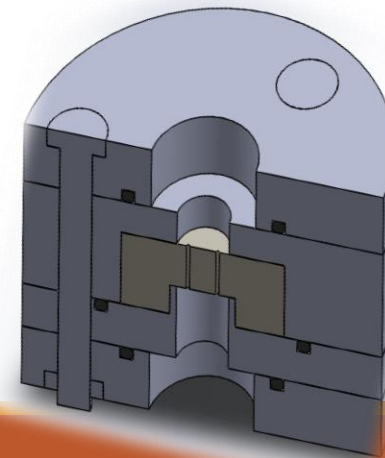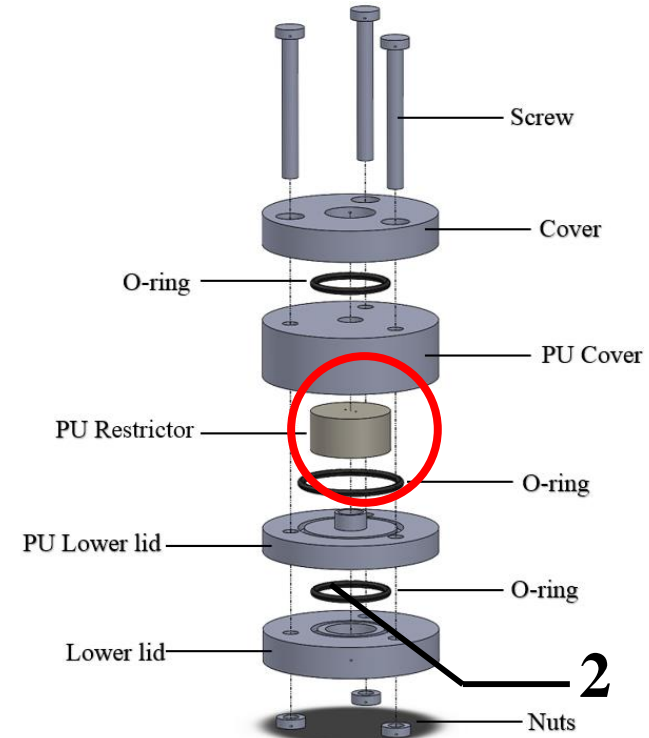
Screw
1
Cover
O-ring
AL Restrictor
2
O-ring
AL Lower lid
3
O-ring
Lower lid
4
Nuts
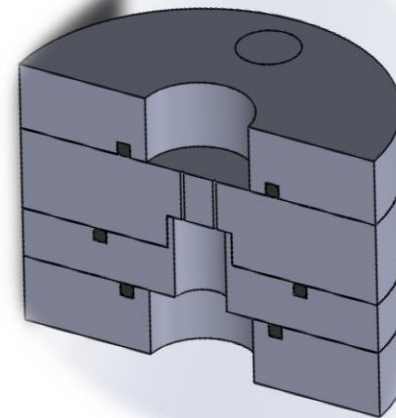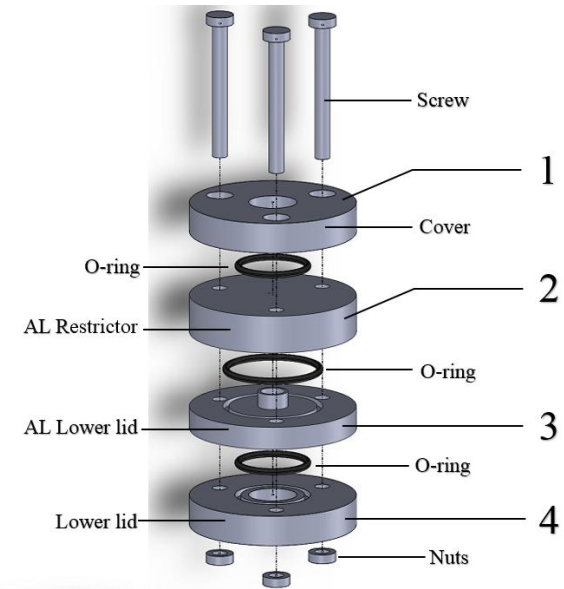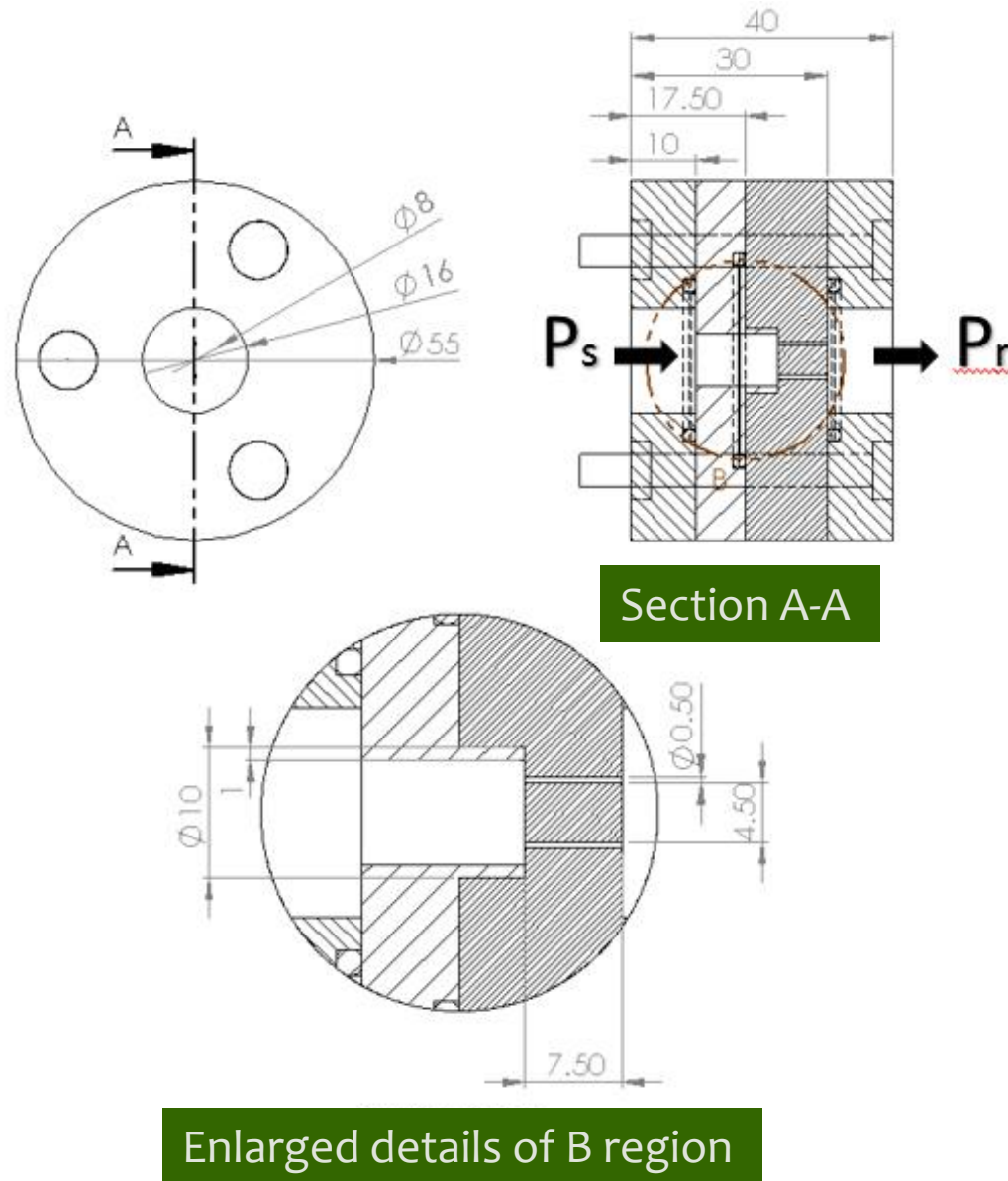
Mechanical Properties of Commercial (Market)/ Laboratory Polyurethanes

	A90(M) Commercial	A90 Lab	A80 Lab	A70 Lab
Hardness Shore A	90	90	80	70
Tensile Strength (Mpa)	20~30	30.2	28.1	26.2
Enlongation %	500~600	450.3	450.3	500.2
Fracture Strength (N/mm)	88~127	80.3	70.3	48.2

The graphs show Flux (Q) vs Temperature (T) and Film thickness (h) vs Temperature (T) at 40bar, comparing AL and PU capillaries.
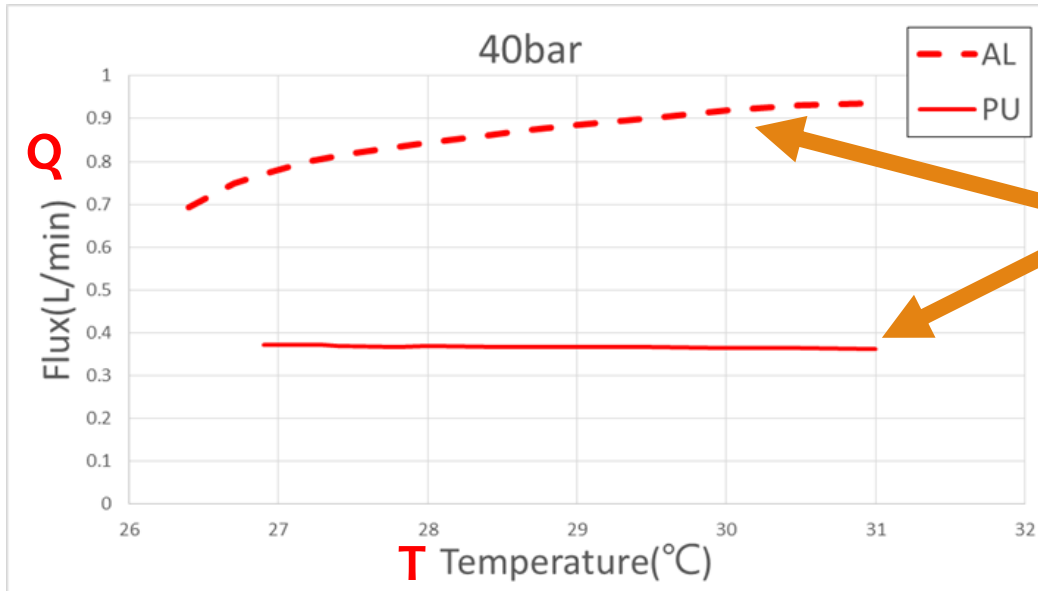
- The change in flux is tremendous for AL capillaries since not only the capillary expands but also the oil becomes less viscous.
- However, the PU capillaries give nearly constant flux because that the softening of PU reshapes the nozzle.

Due to greater Pr and flux
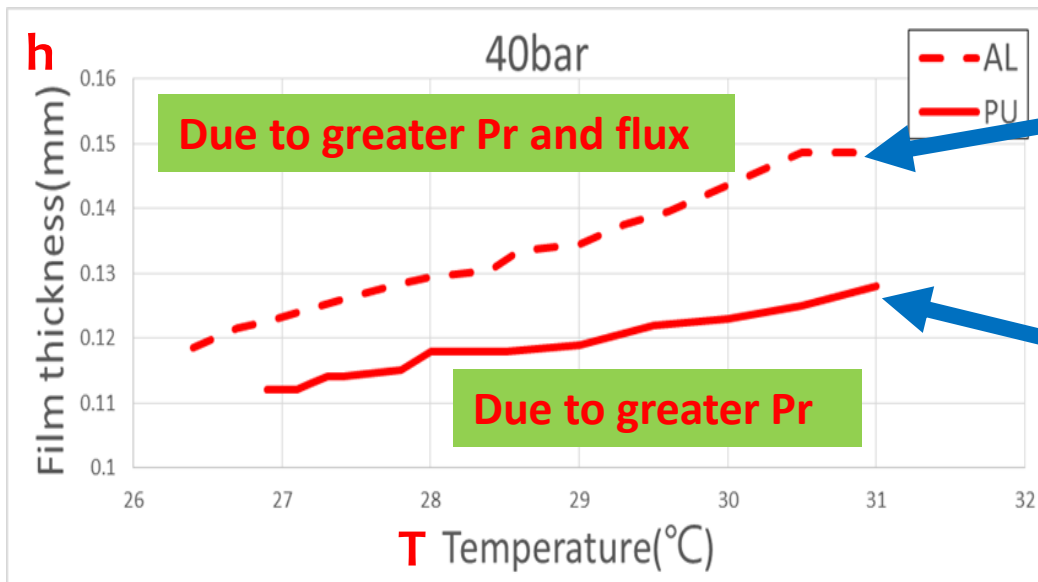
Due to greater Pr

- Due to the surge of flow rate, the film thickness arises 30 μm.
- But only half for PU capillaries due to the greater P_r from sharper nozzle.

$Rc=(Ps - Pr)/Q$
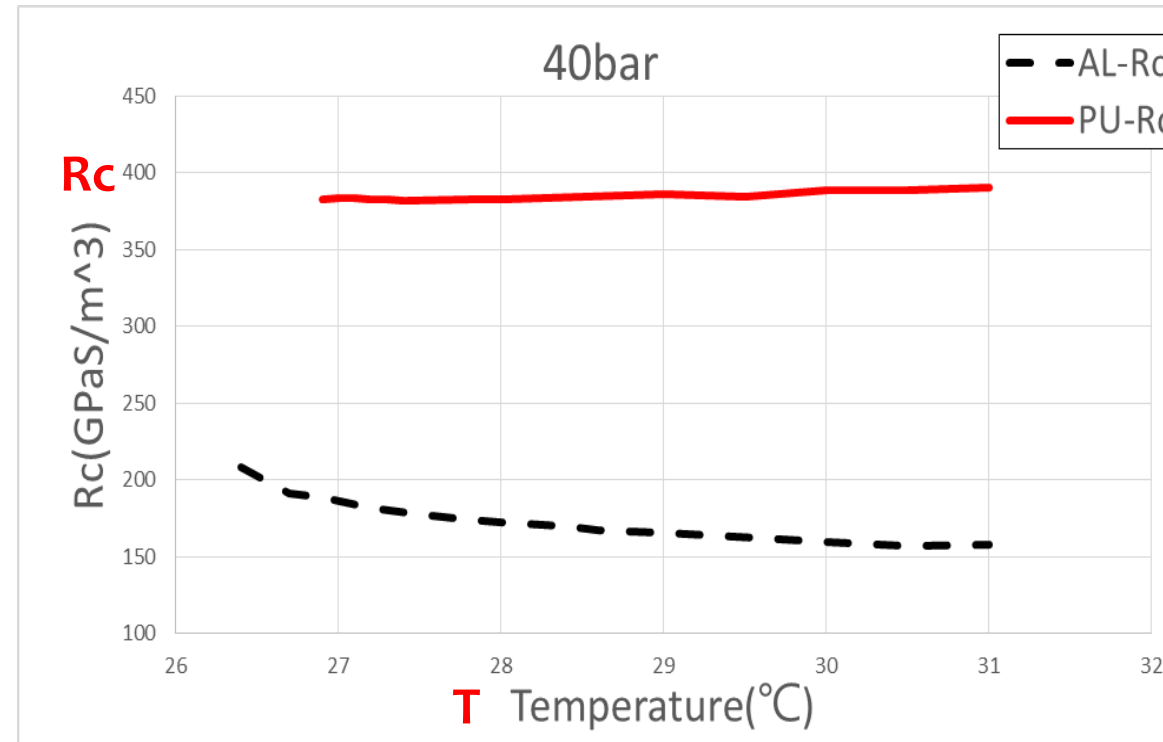
From the pressure difference and the flux, we can calculate the impedance Rc. The impedance of PU restrictor is much stable than that of the AL one.

Influences of Hardness on Flux Compensation

- **Softer PU** is more sensitive to the pressure caused by load. For instance, at Ps= 20 bar, we can see more flux compensation in cases of A70 and A80. But it might be teared apart or lead to leakage for high Ps.
- **Harder PU's** respond when Ps is close to 50 bar.

No compensation for AL capillary

Little compensation for hard PU

Compensation in flux for hard PU at 40-50 bar

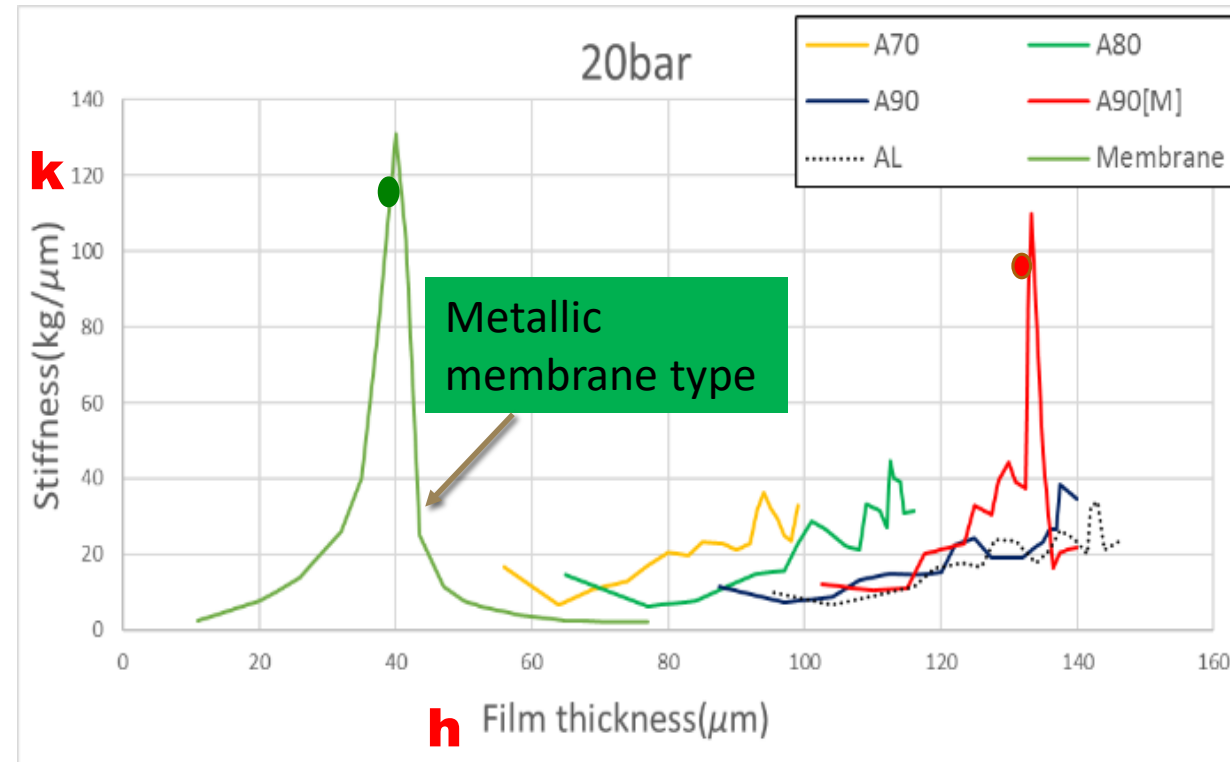**20 bar**

50 bar

Q

Q

F   load(kgf)
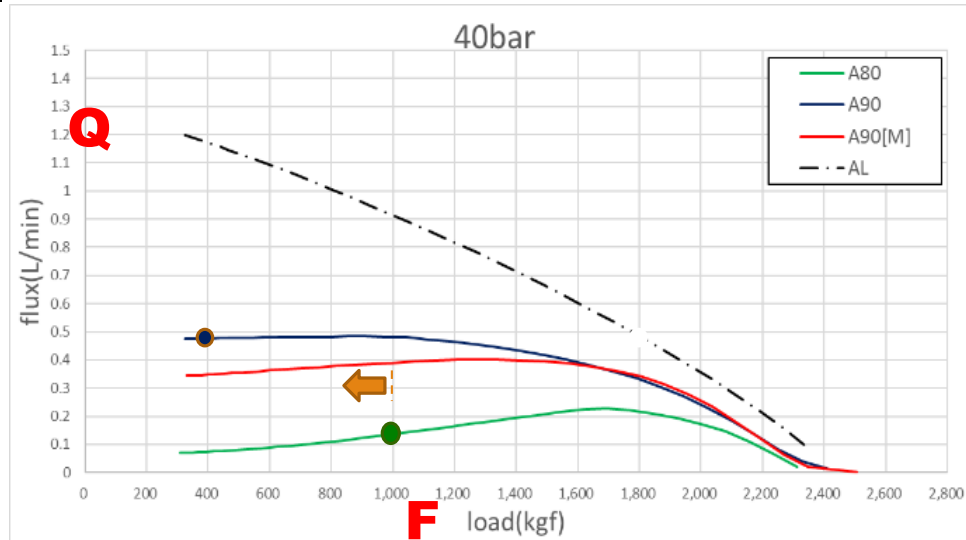
F   load(kgf)
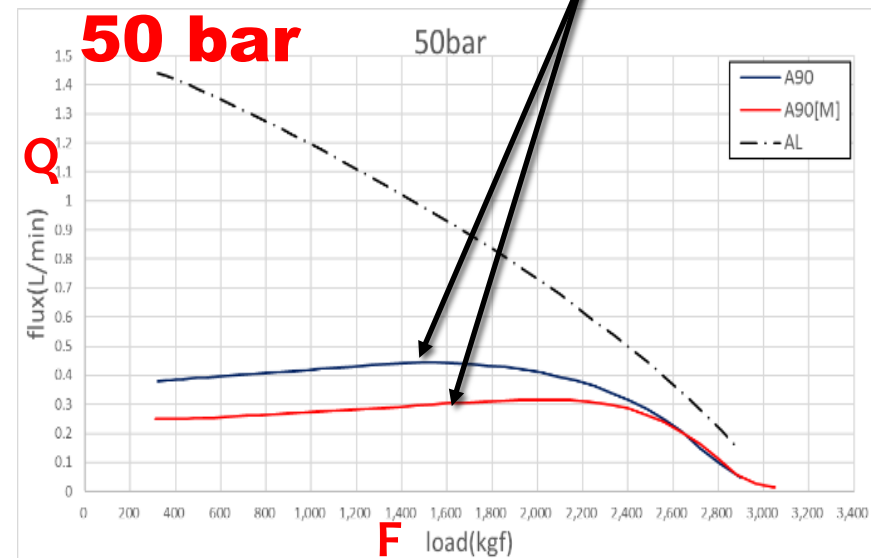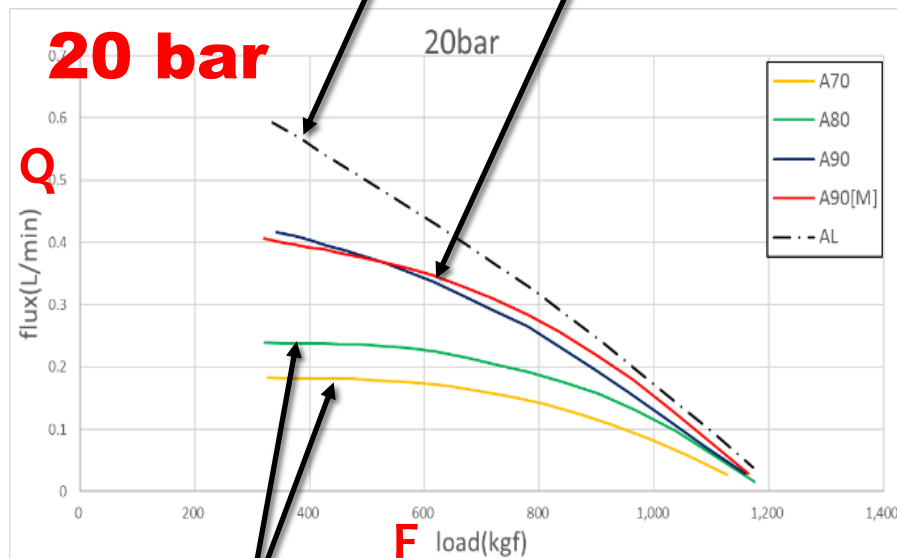
Compensation in flux for softer PU

Static Stiffness of Bearings

For Ps= 20 bar, the PU system can generate the stiffness close to that of the traditional membrane type. However, its **film thickness (135μm) is much greater than that of the membrane one (40μm).**
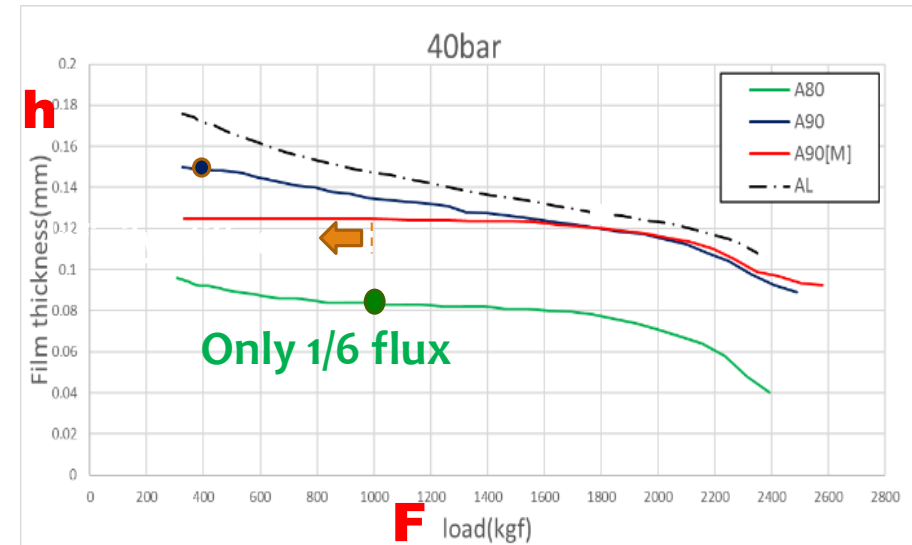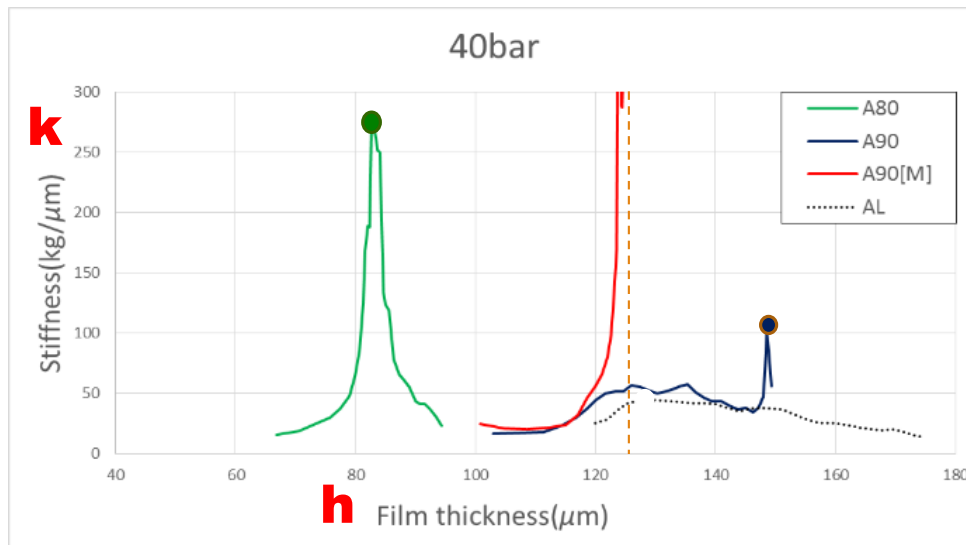
20 bar

40 bar

- **The highest stiffness occurs at where the flux compensation is the most effective (dQ/dF is maximum)**
- For A90[M], infinite stiffness can take place in a wide range of load. **Good performance is observed between 300 kg and 1800 kg.**
- For load around 1000 kg, **A80 is a good choice due to the very low oil flux.**

Conclusions

(1) PU restrictor is more stable than the metallic one with respect to temperature variation.

(2) Compared to the metallic capillary, the PU capillary is reshaped to a converging nozzle for which the oil flux can be reduce to about 1/10 under low loading, and half at high loading.

(3) The soft PU demonstrates flux compensation under low supply pressure while the hard PU only responds to greater supply pressure. Proper hardness is needed to prevent the capillary from leakage.

(4) Raising the supply pressure P_s will move the max flux toward the high load region. But max flux does not yield the best stiffness; The greatest stiffness happens where flux compensation is the most effective (dQ/dF is maximum, where Q=flux, F=load).

(5) The optimal combination of PU hardness and supply pressure depends on the performance of stiffness and the oil flux in demand. Infinite stiffness over a wide range of loading can be achieved.

Thank you