Developing healthy piston ring pack systems – oil control and its limit
活塞环组健康系统概念与开发---控油及其极限

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MITMECHE

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The Second World Internal Combustion Engine Conference

Development of Power Cylinder Unit (PCU)

Multiple components; multiple constraints, and targeting efficiency

System optimization

Operational parameters (Speed, load,…)

Cylinder bore/liner
Liner finish
Bore distortion, Temp

Engine lubricant
Viscosity, additives
volatility

Piston and piston rings

CONSTRAINTS

Oil consumption
Blowby
over engine lifetime

Wear and carbon deposit under control

EFFICIENCY

Friction
Compression height
Cost

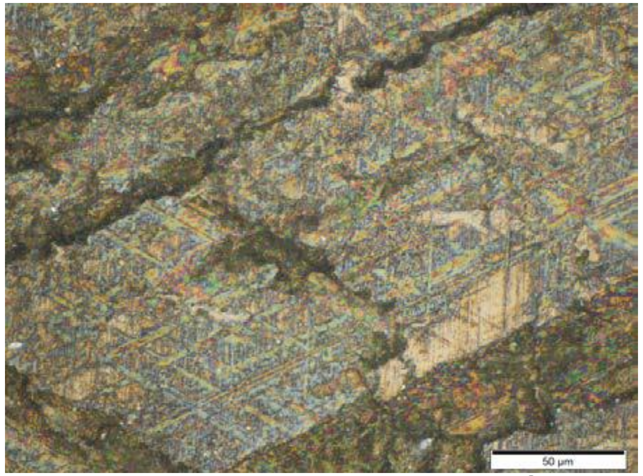
Partially involved:

- Particle emissions
- Oil dilution

A ‘healthy’ ring pack system: supply oil up to the top ring and release oil through piston/groove and gaps

(Originally proposed in February 2008, consortium on lubrication in IC engines, MIT)

Tribo-film on top of the liner



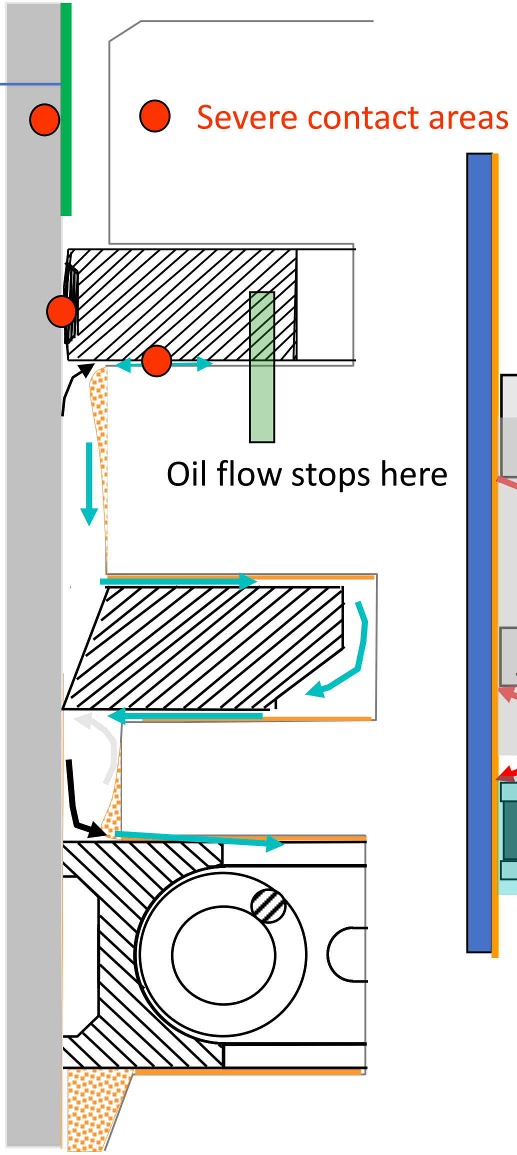
50µm

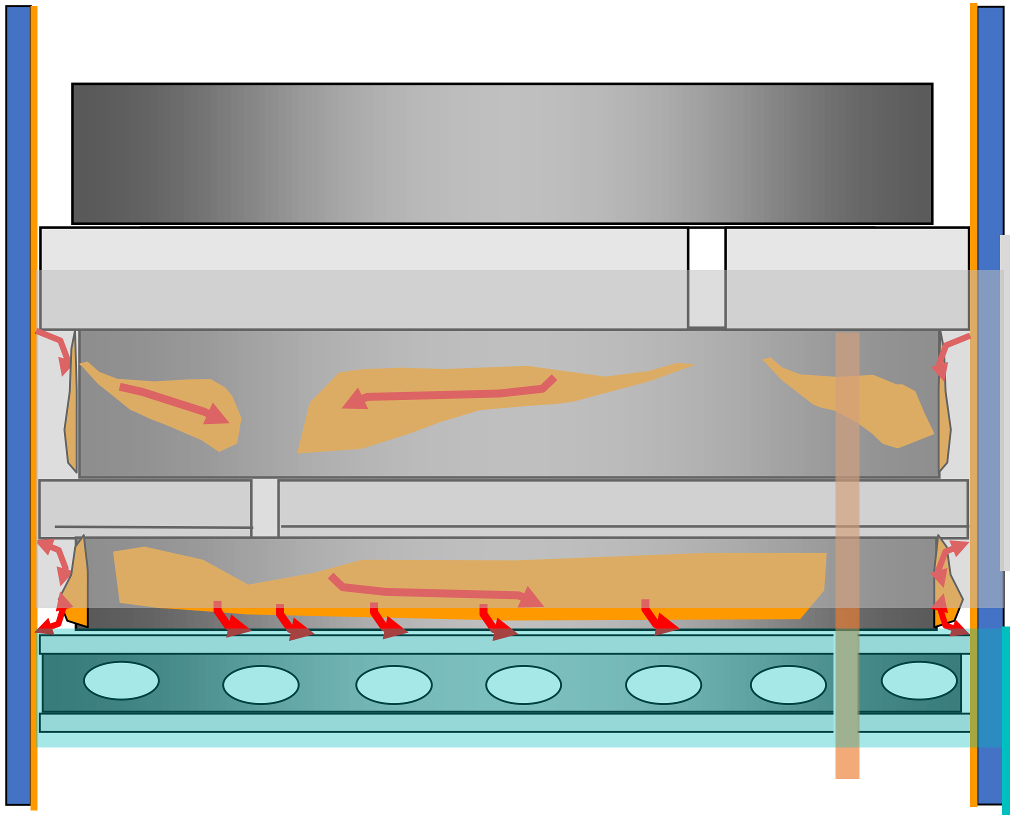
Presence of tribo-film on the liner at the Top ring reversal

HD diesel after 80kmi

LAYO AJAYI, Argonne National Lab

March 2017 MIT lube consortium meeting





Oil and Gas regulation

- Ring dynamics
- Gas flows
- Oil redistribution
- Ring/Land/groove design
- Rings/distorted-bore interaction

Oil control and release

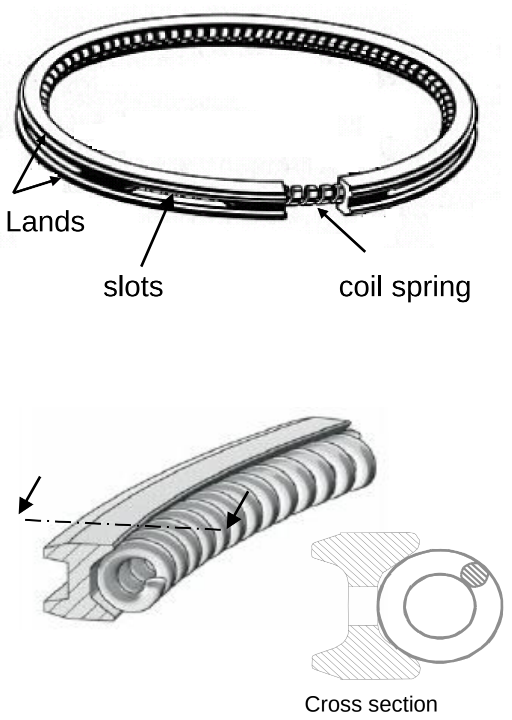
- OCR and liner finish
- Piston secondary motion
- OCR Up-scraping
- Oil/gas interaction
- Drainage

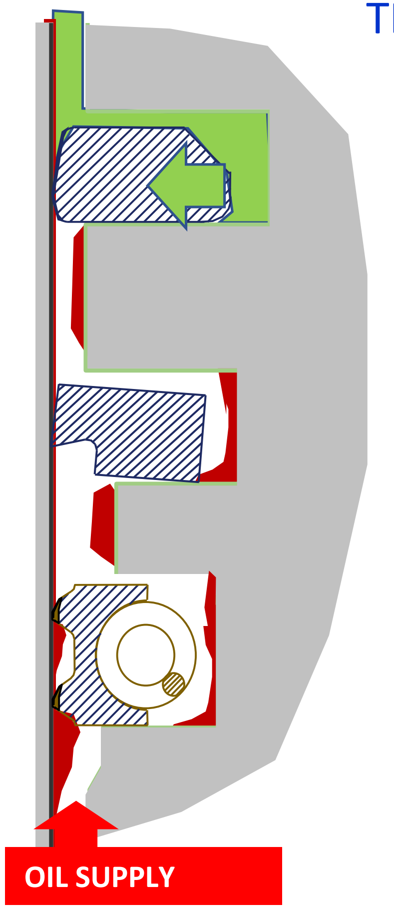
Consequence: minimize wear, carbon deposit, and LOC with economical solutions

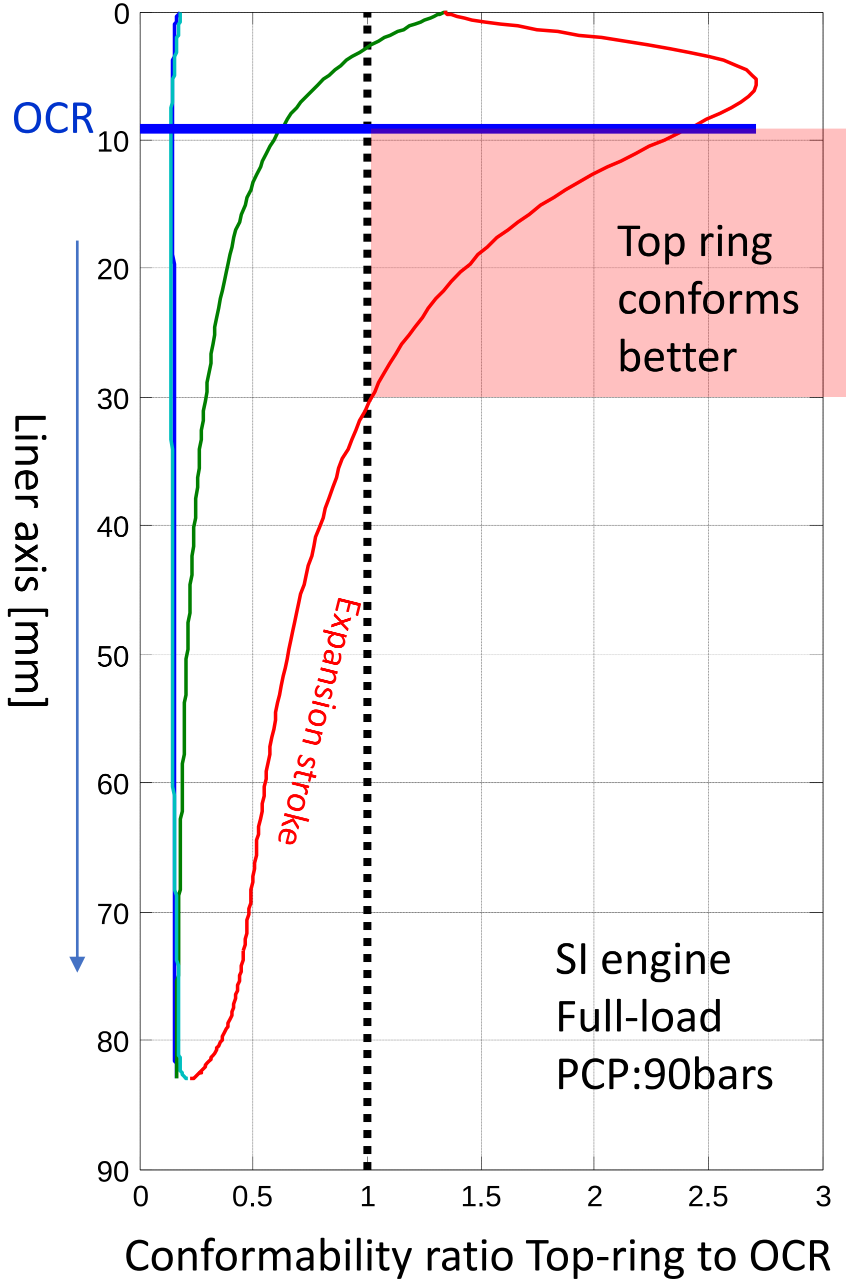
Oil control along the liner

Structure Level requirement: The main concern for liner oil film thickness control is between the oil control ring and the top ring under high cylinder pressure

Two Piece Twin-land Oil Control Ring (TLOCR)

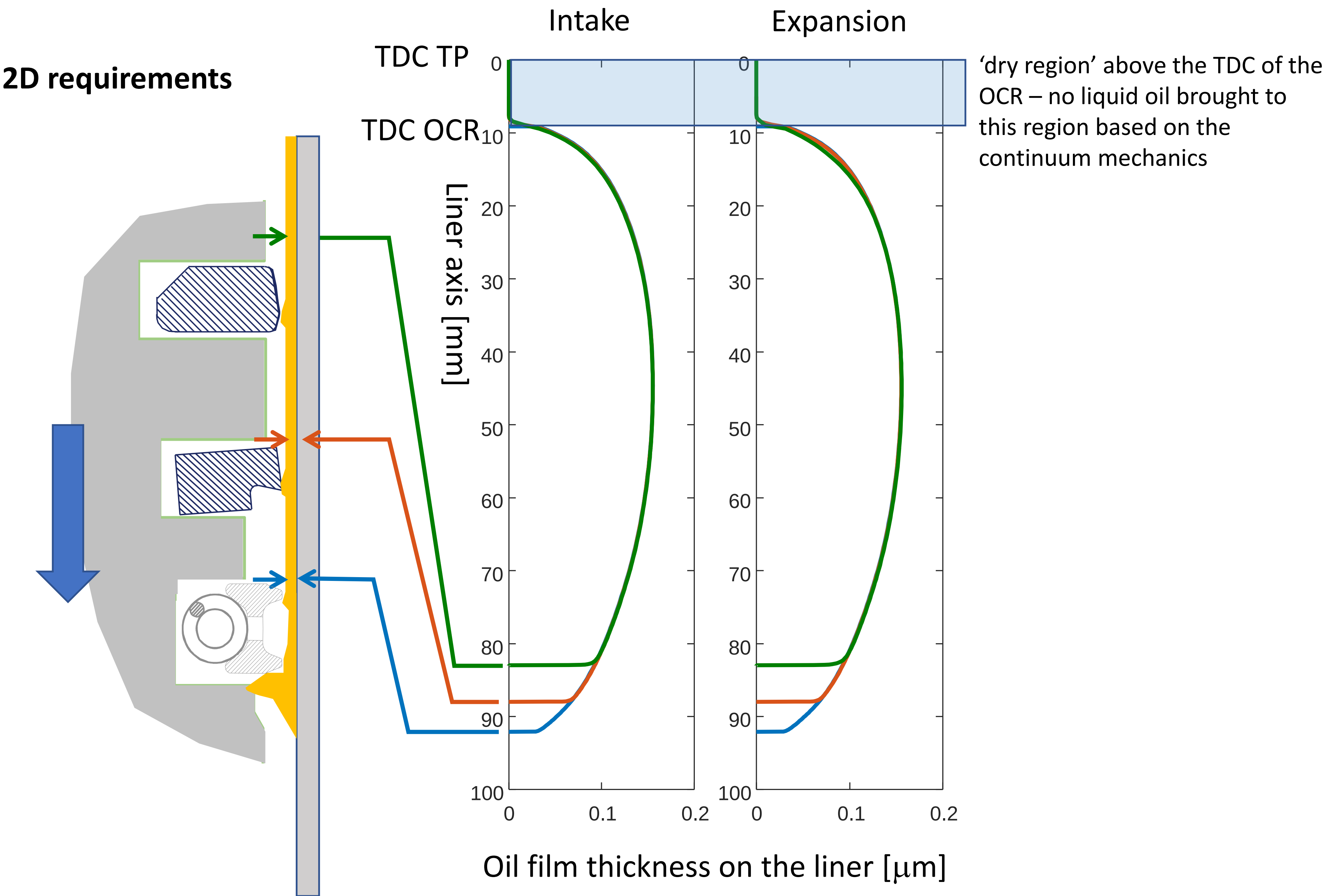




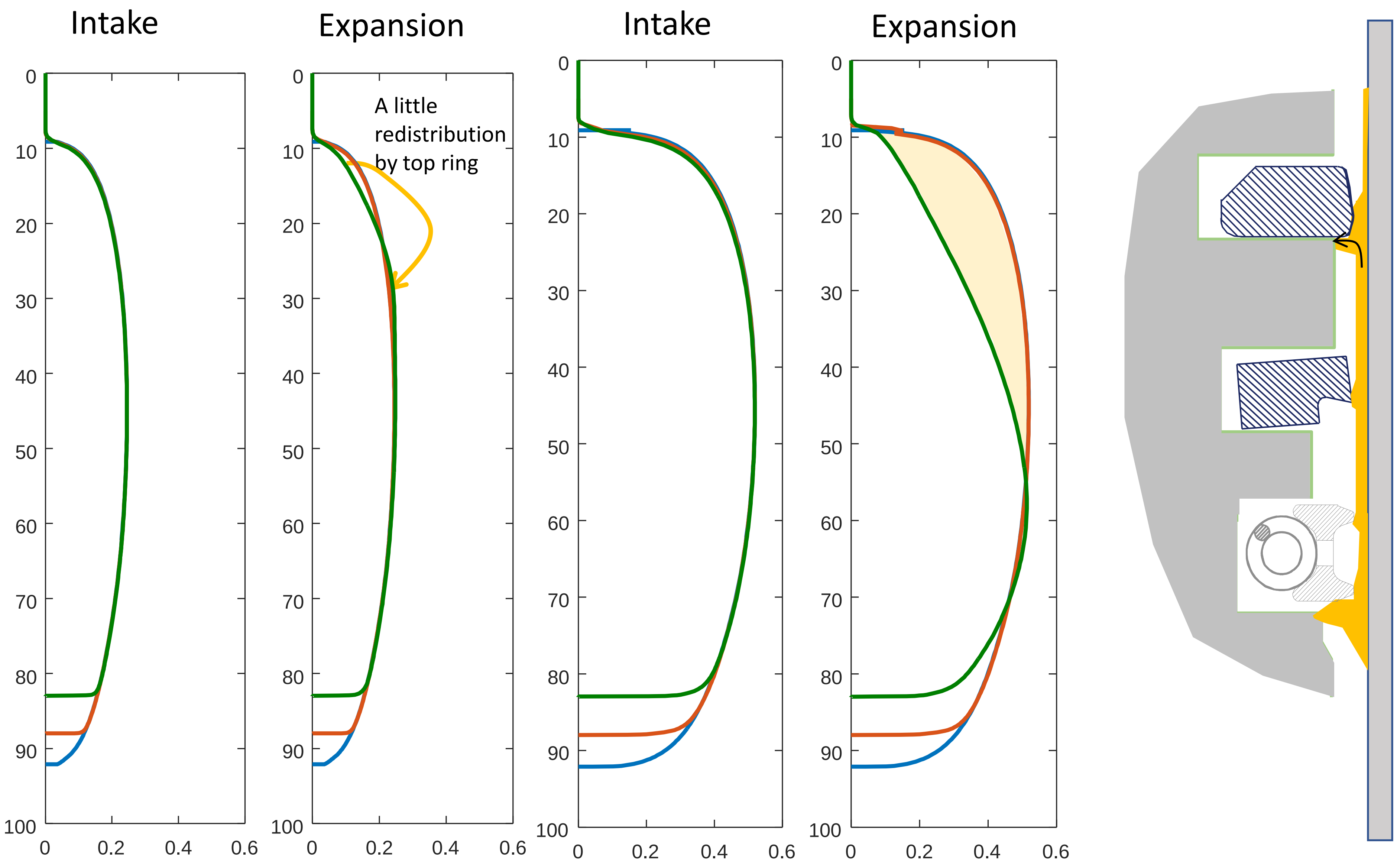


OCR needs to conform to the distorted bore in this area.
If not, the top ring can directly scrape the oil from the liner to the second land.

Expected behavior: top two rings simply slide over the oil film left by the OCR without scraping



Loosening oil control by the OCR, top ring starts to scrape the oil to the second land

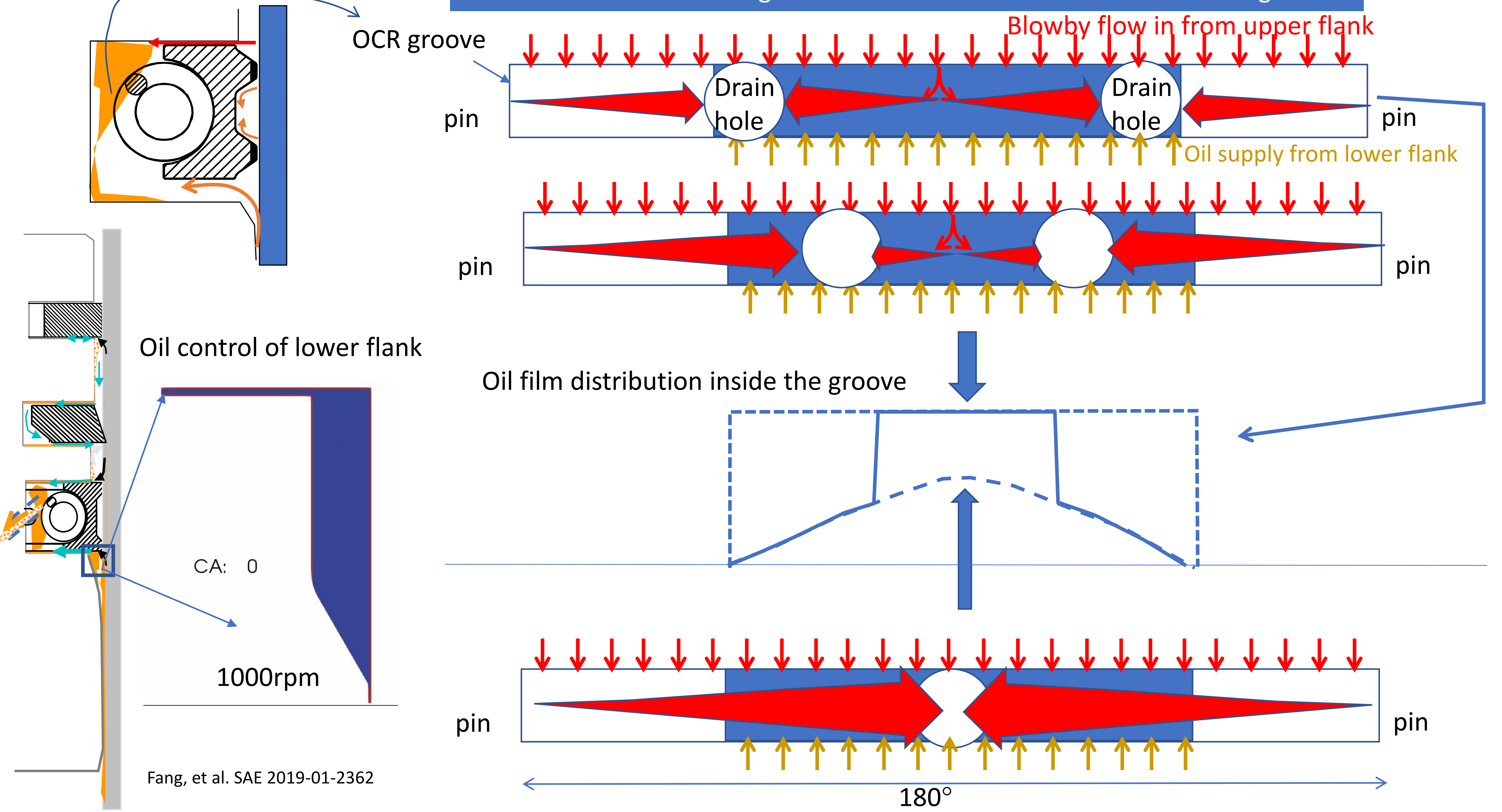


It is safe to say that OCR has to control the oil film thickness on the liner to sub-micron level

For a healthy ring pack

- Without considering the OCR gap, the oil left by the OCR is slid over by the top two rings without net transport to piston
- Two distinctive regions – below and above the TDC of the OCR, the latter has been called dry region
- There is in general an oil redistribution to the lower part of dry region by the top ring in compression stroke
- In this picture, there is no oil supply to the dry region to help build tribo-layer. Other processes have to be involved.

Effects of Drain hole arrangement on oil accumulation inside the OCR groove



Fang, et al. SAE 2019-01-2362

Through the oil control ring, there are four different sources that can introduce additional leakage to ring pack upper regions (Except Source 3, all the rest depends on oil accumulation inside the groove)

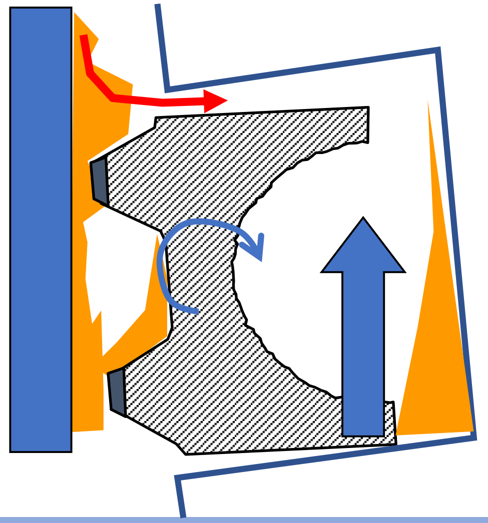
Ring/liner interface

1. OCR up-scraping

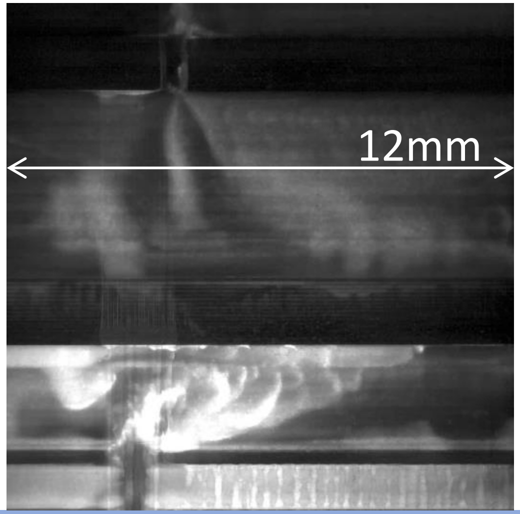
Lower part of up-stroke due to the piston tilt effect;

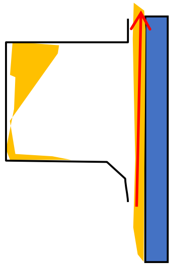
Y. Liu Ph.D. thesis, 2017 MIT

Critical:
OCR design
Piston secondary motion
(for TLOCR primarily)



3. OCR gap, scraped down by top two rings



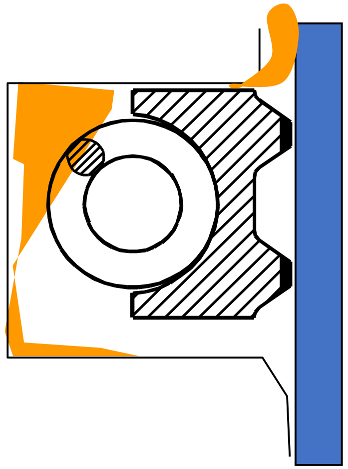


March 2020, Ahling
2000rpm/700mbar
Magnified, BDC+2

Critical:
Piston secondary motion
Skirt lubrication
Top two Ring/liner interaction

OCR groove

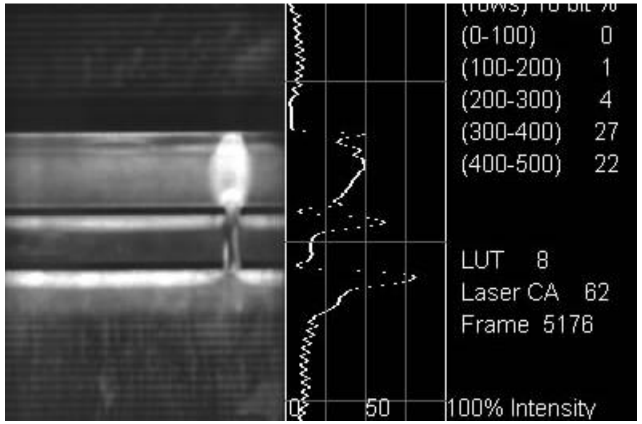
2. Oil supply from the OCR upper flank clearance

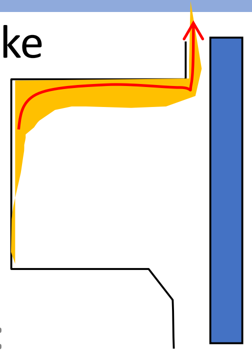


- TLOCR unlikely with only moderate throttle

Critical:
OCR design
Throttle level

4. OCR gap from the groove in intake (only in throttled conditions)



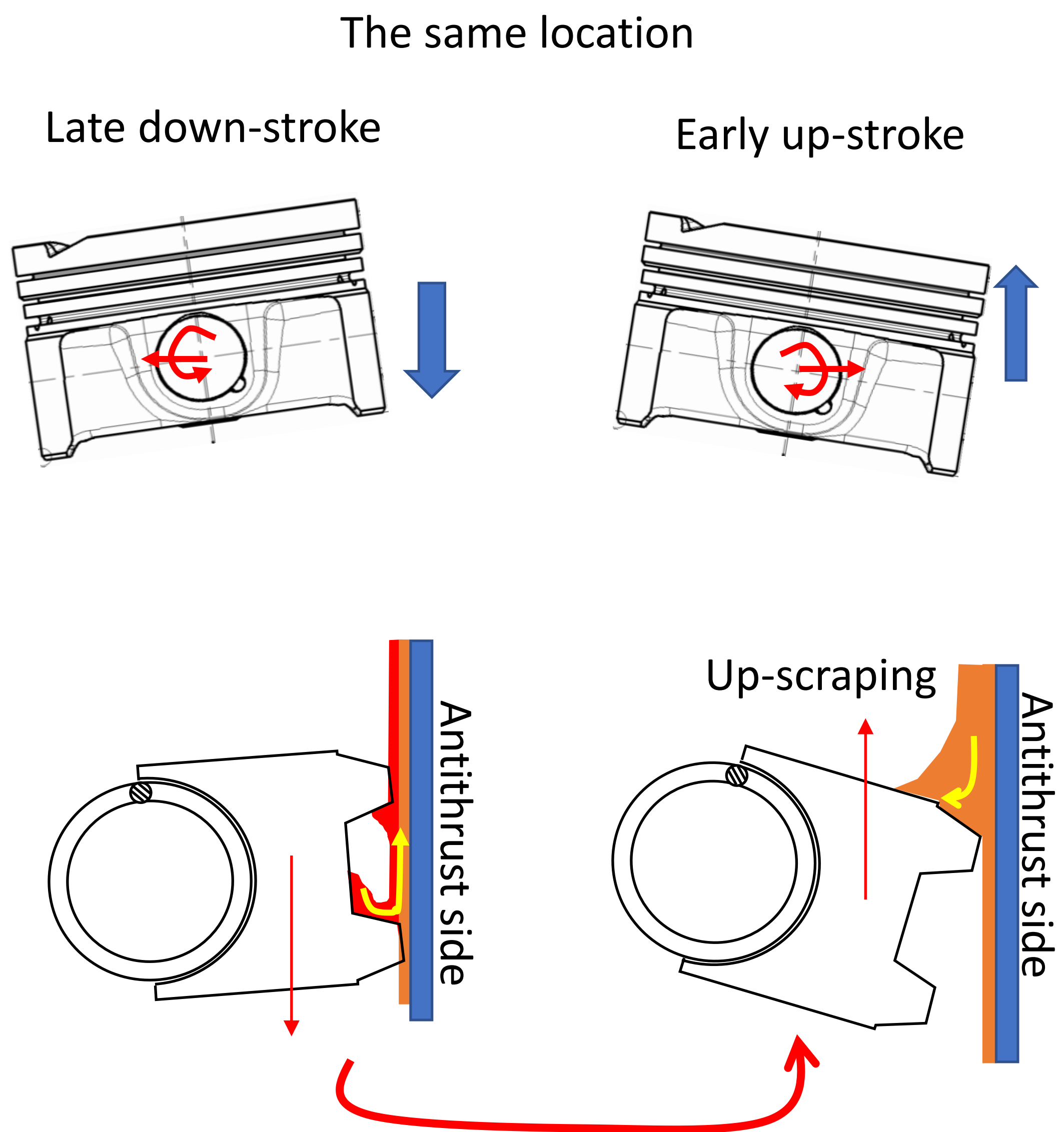


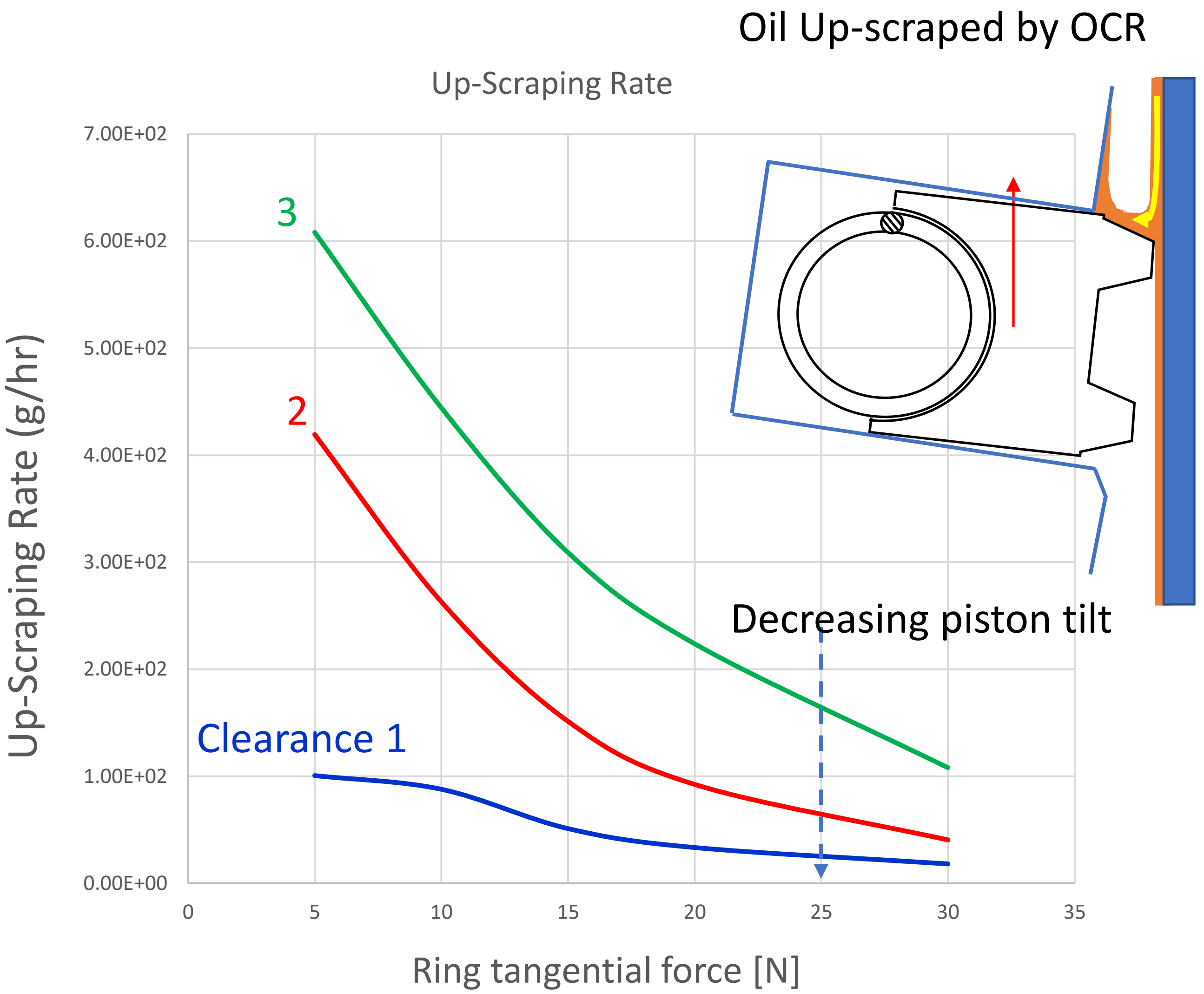
Critical:
Oil accumulation inside the groove

the leakage along the circumference of TLOCR – up-scraping

- piston tilt from secondary motion
- oil bridging to the liner – oil accumulation inside critical

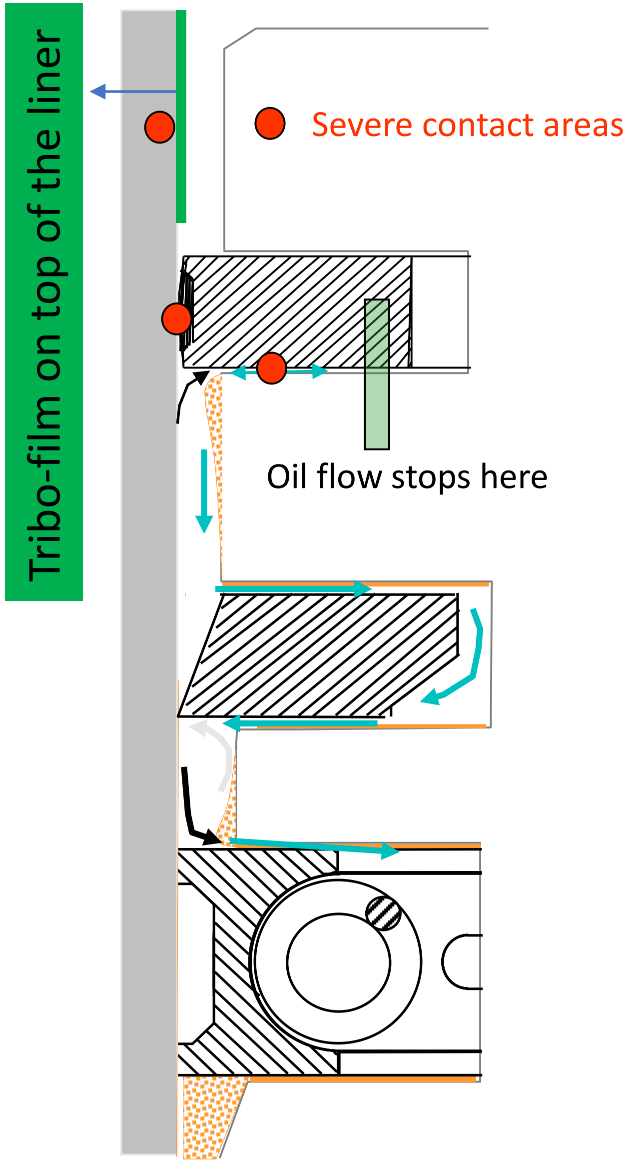
(SI engine example, bore diameter is 82.5mm)
Results from 3D oil transfer model, Y. Liu, Ph.D. thesis, 2017



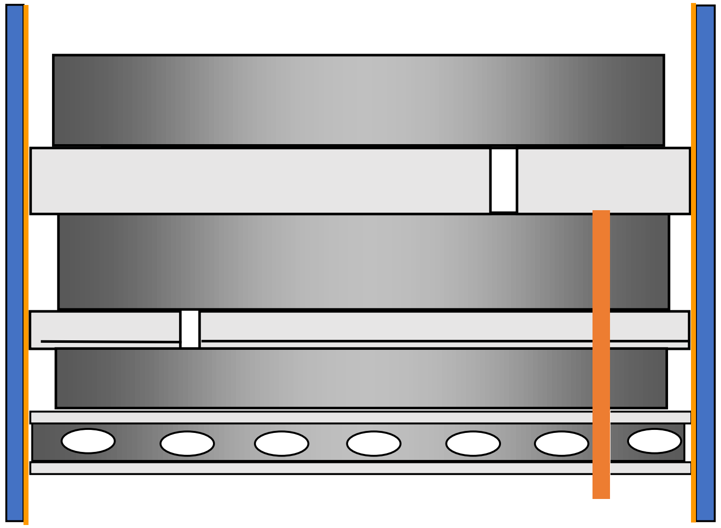


Lubricant is needed to protect the piston, rings, and liner, especially the following two critical regions while meeting oil consumption requirement

1. Lower flank of the top ring groove
2. Top of the liner, i.e. dry region (above TDC of OCR) to build tribo-layer

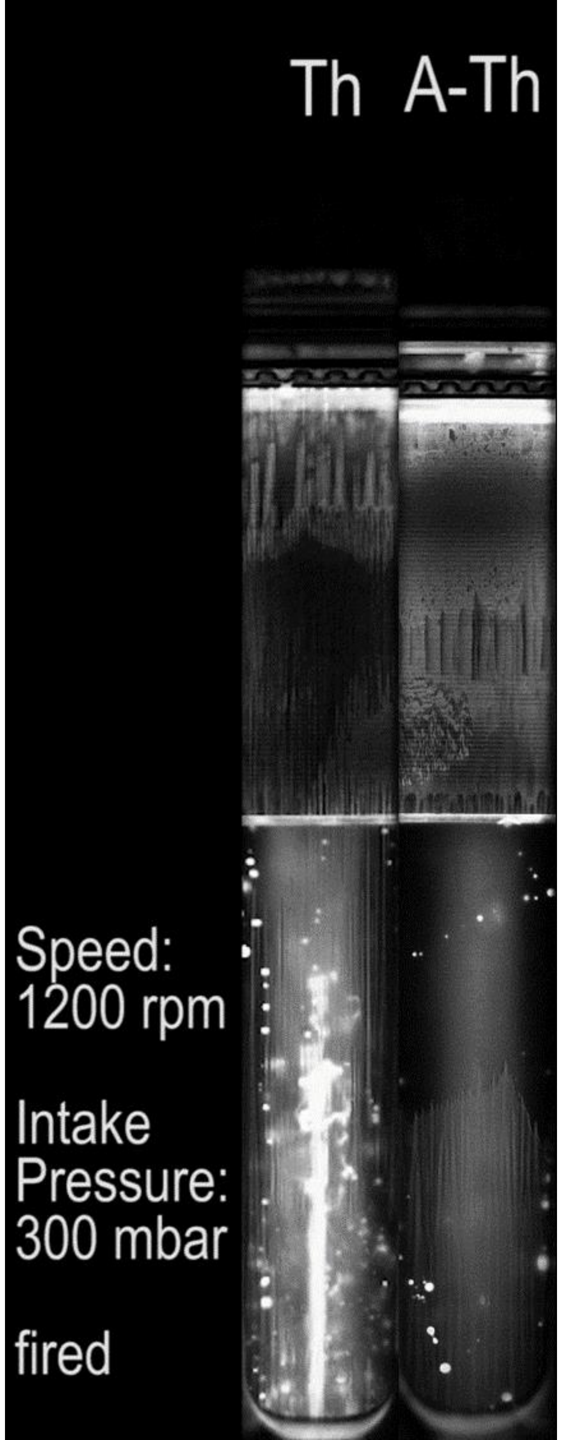


- What is required to ensure sufficient oil supply to these two critical regions? How do we define “sufficient”?
- Can this requirement be satisfied with only OCR gap as the additional oil supply path? What needs to be done in upper regions?
- What are the design requirement to eliminate the OCR up-scraping and pumping to the third land or to reduce them to a sufficient low level such that it does not introduce net transport into upper regions, i.e., these two sources won’t contribute to LOC? Is this the ultimate healthy system that we are trying to reach?
- What is the LOC of such as system? This would represent the theoretical limit of the LOC. How do we want to predict this LOC?

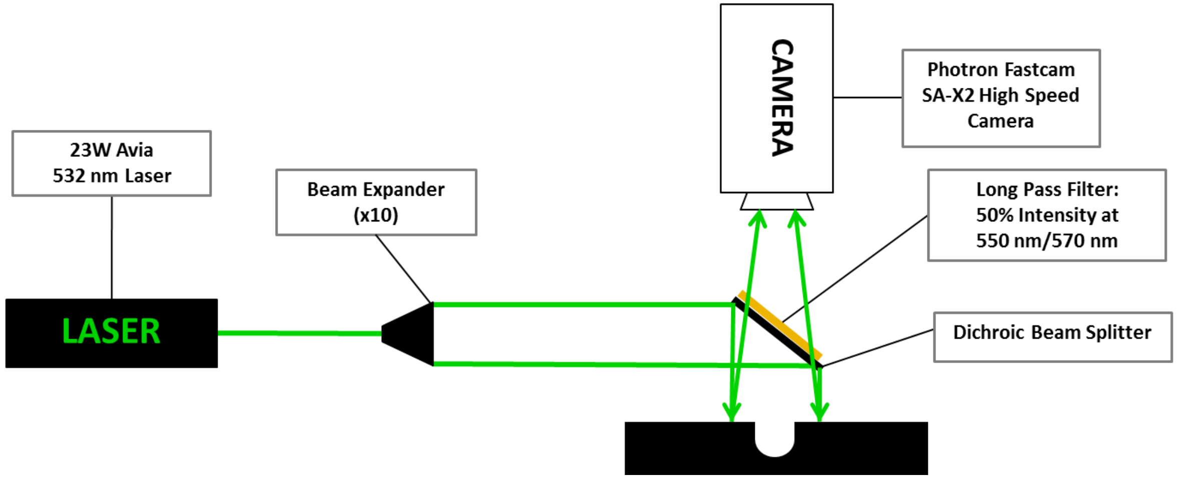


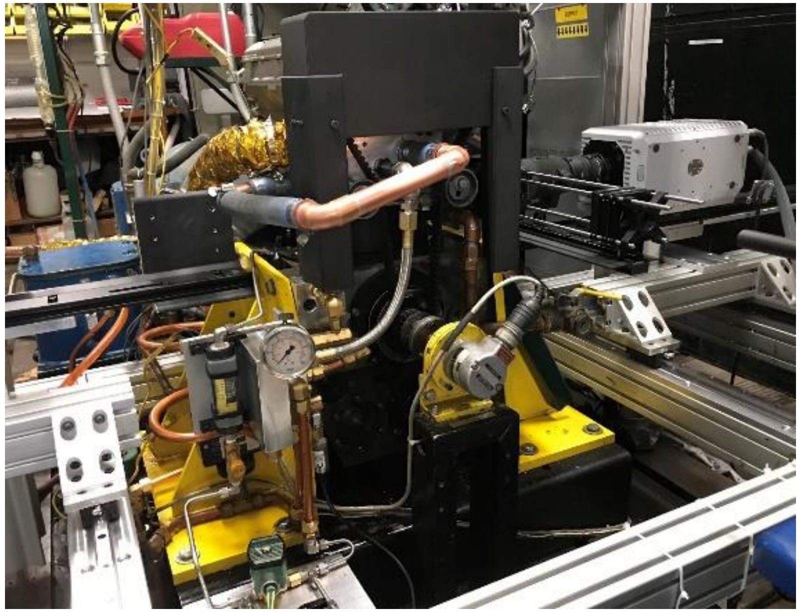
Ability to answer these questions critical to

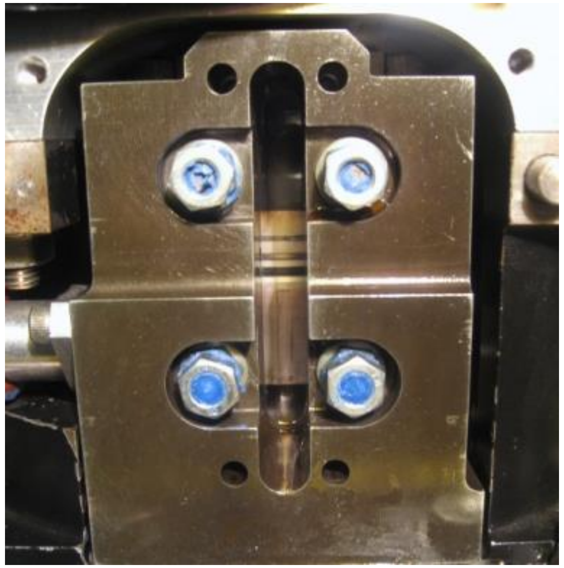
- Determining aftertreatment capacity
- Determining Additives concentration in the lubricant
- Standardizing piston ring pack design at different levels
- Synchronizing design targets, tool application, and tool development



- High speed system – up to 72000frame/second
  - 23W Avia Laser
  - Photron SA-X2 High Speed Camera
  - 10x Beam expander
  - Dichroic beam splitter and Long Pass filter used



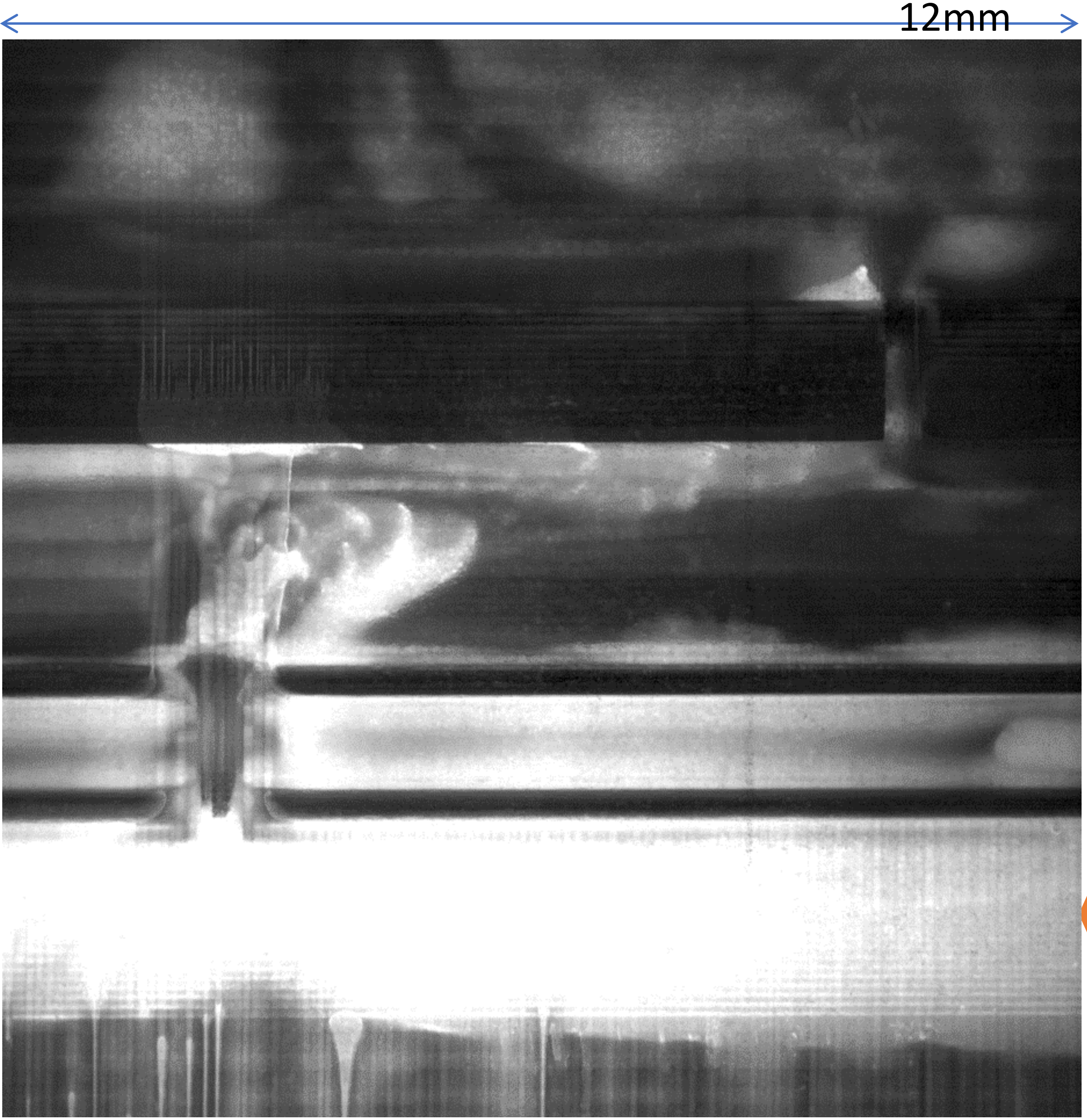


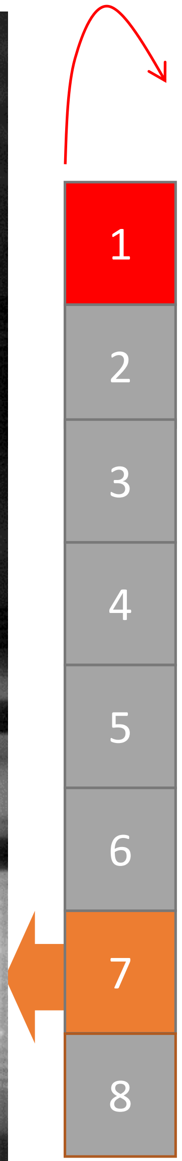


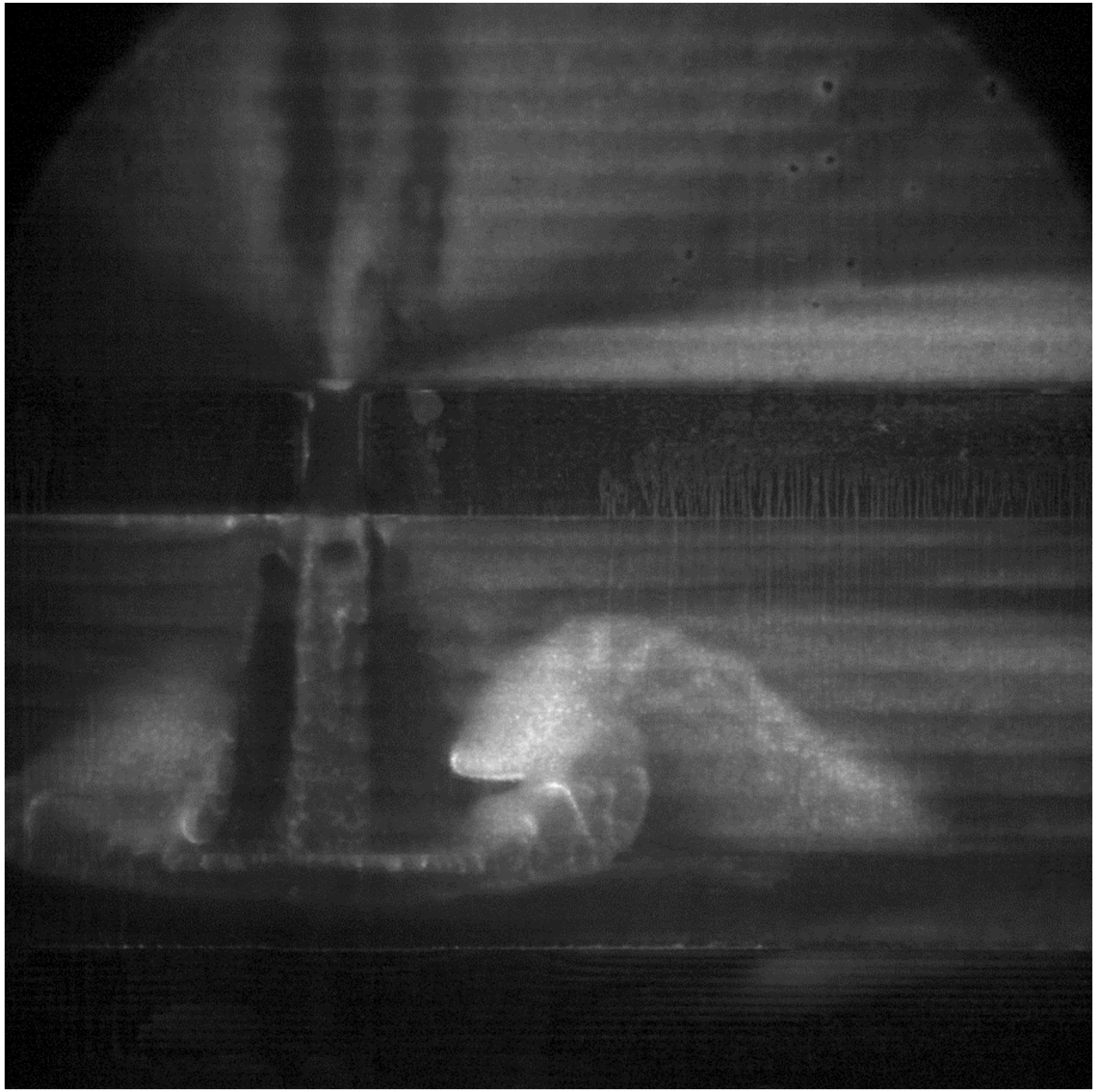
Top two ring down-scraping

Magnified view

Enhanced bridging due to strong vortex



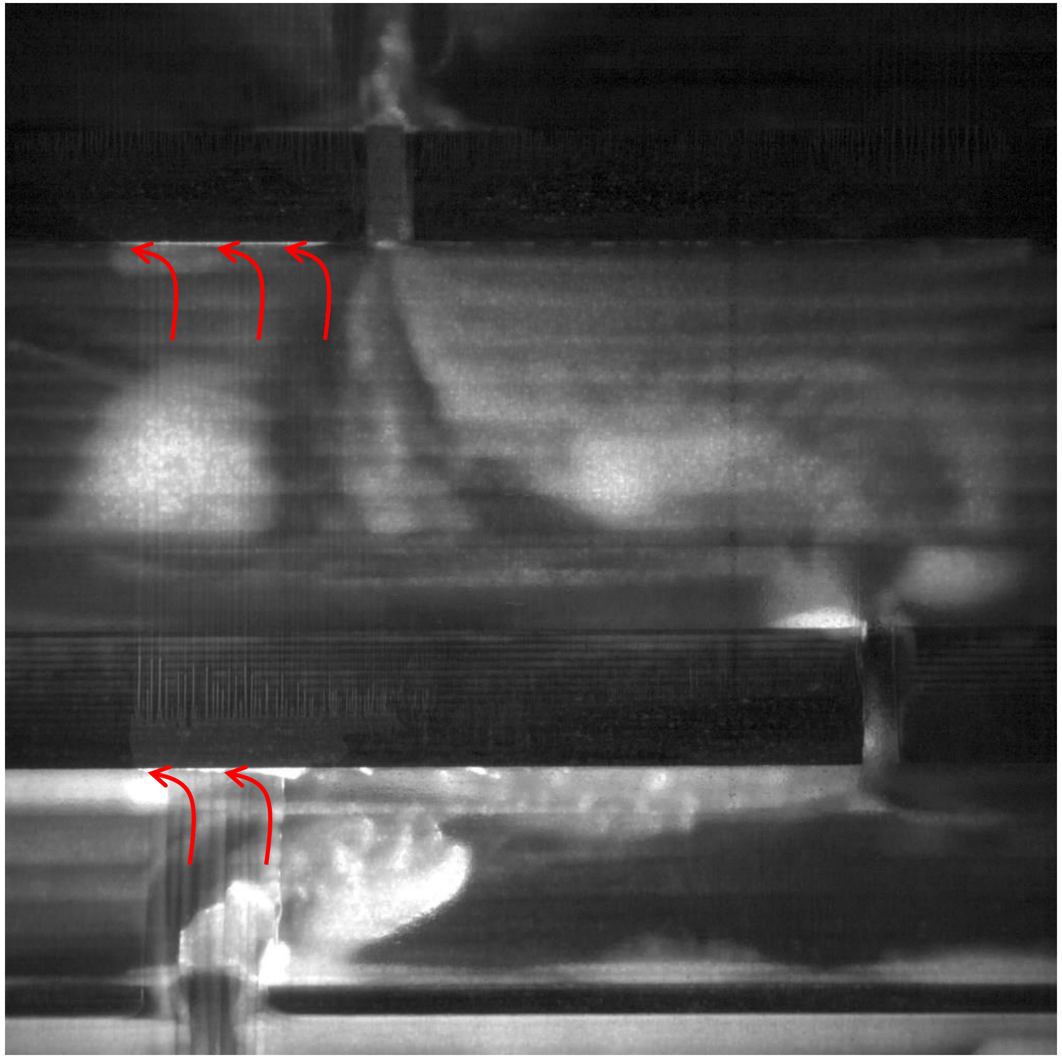


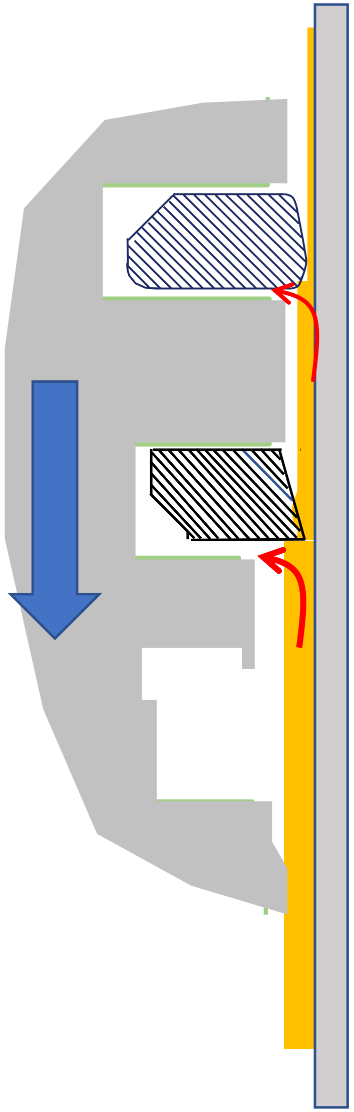


650rpm/700mbar/TLOCR - intake

650rpm/700mbar/TLOCR – compression/expansion

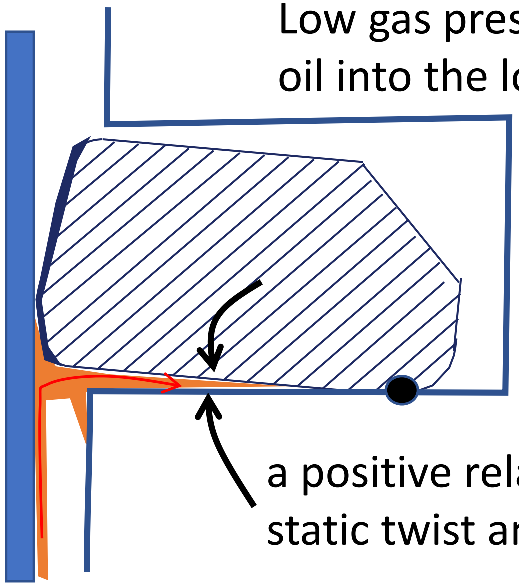
Top two rings scrape down excessive oil around the area OCR gap travels





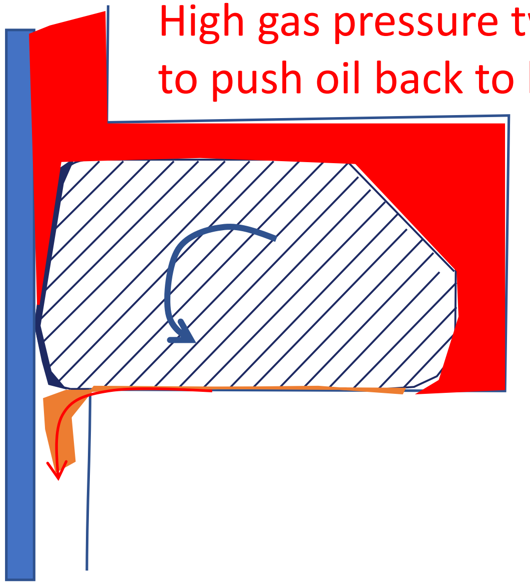
Pumping and squeezing to wet top-ring lower flank without leaking to the groove

Low gas pressure – admitting oil into the lower flank



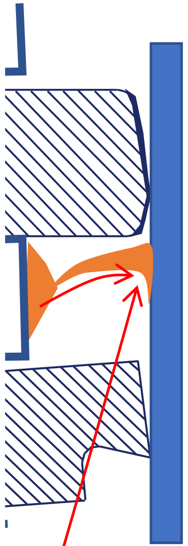
a positive relative angle by static twist and groove tilt

High gas pressure twists the ring to push oil back to lower region

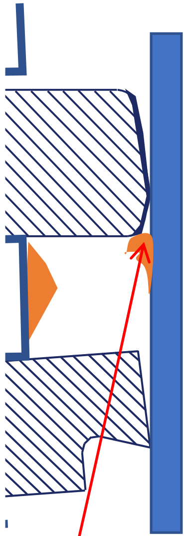


Enhanced bridging driven by strong vortex next to the top ring gap

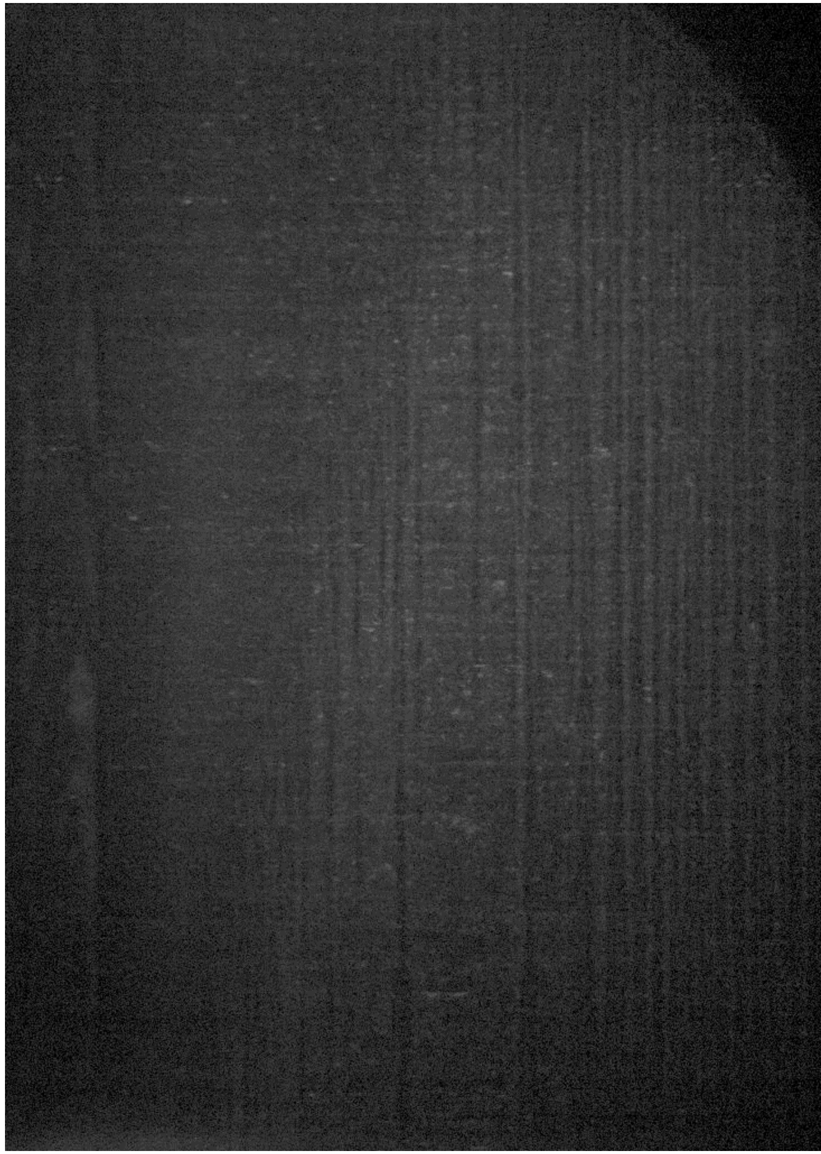
Oil is entrained to the liner from the 2nd land from the eye of the vortex

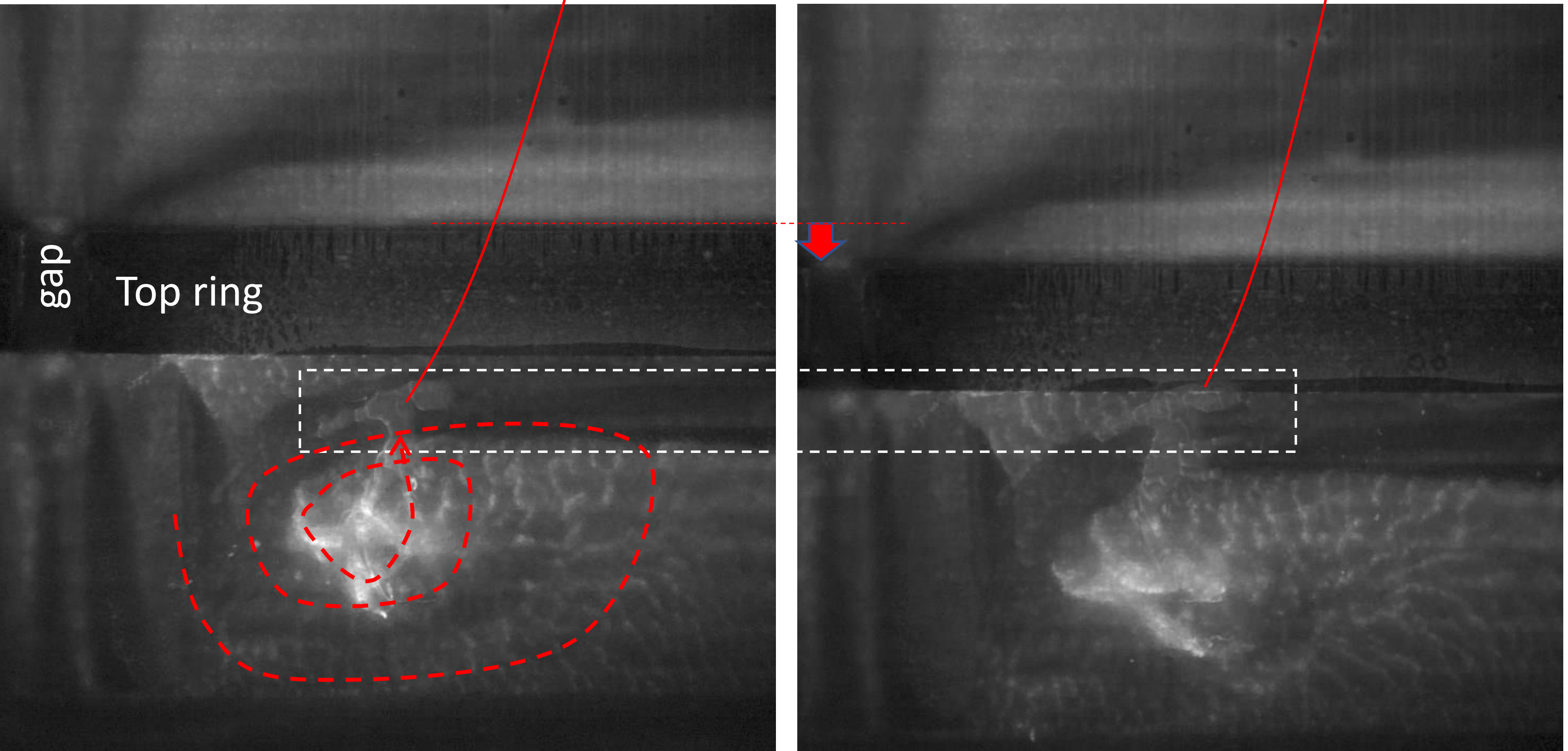


bridged oil on the liner starts to interact with the top ring running face



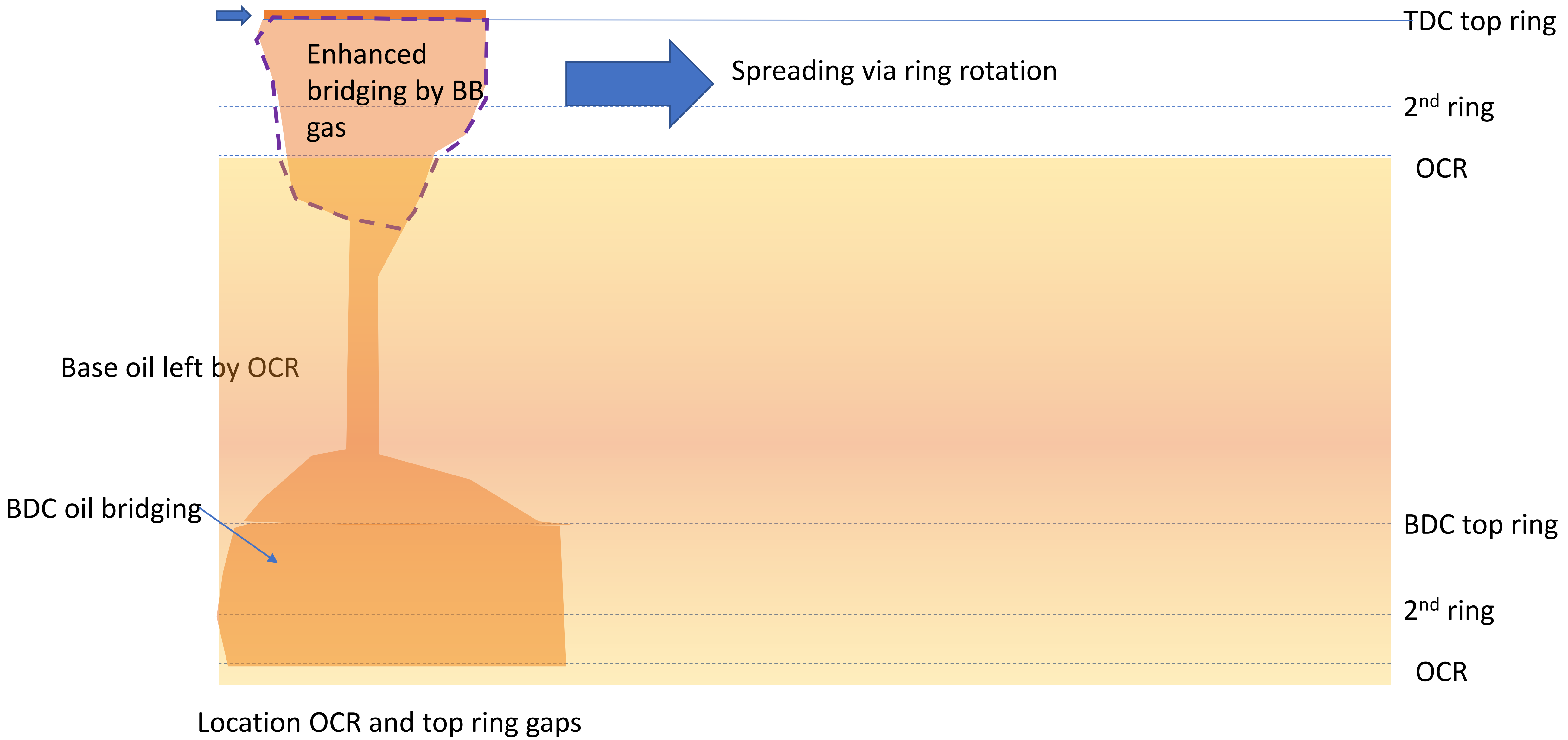
Oil streaks left on top of the liner after ring leaves





Situation OCR gap and top ring gap are close to each other:

- oil can be spread to the top of the liner to help form tribo-layer – source of oil consumption as well
- Ring rotation can help spread along the circumference



Situation that top ring gap is away from the OCR gap

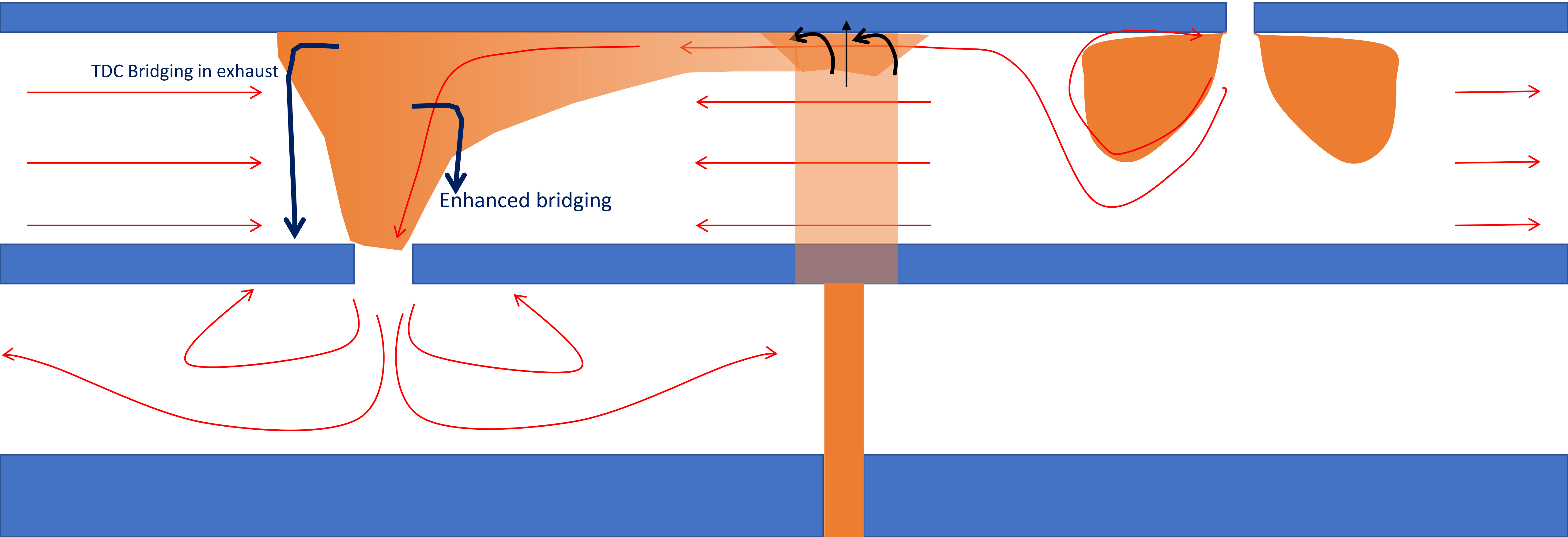
Redistribution toward the 2nd ring gap

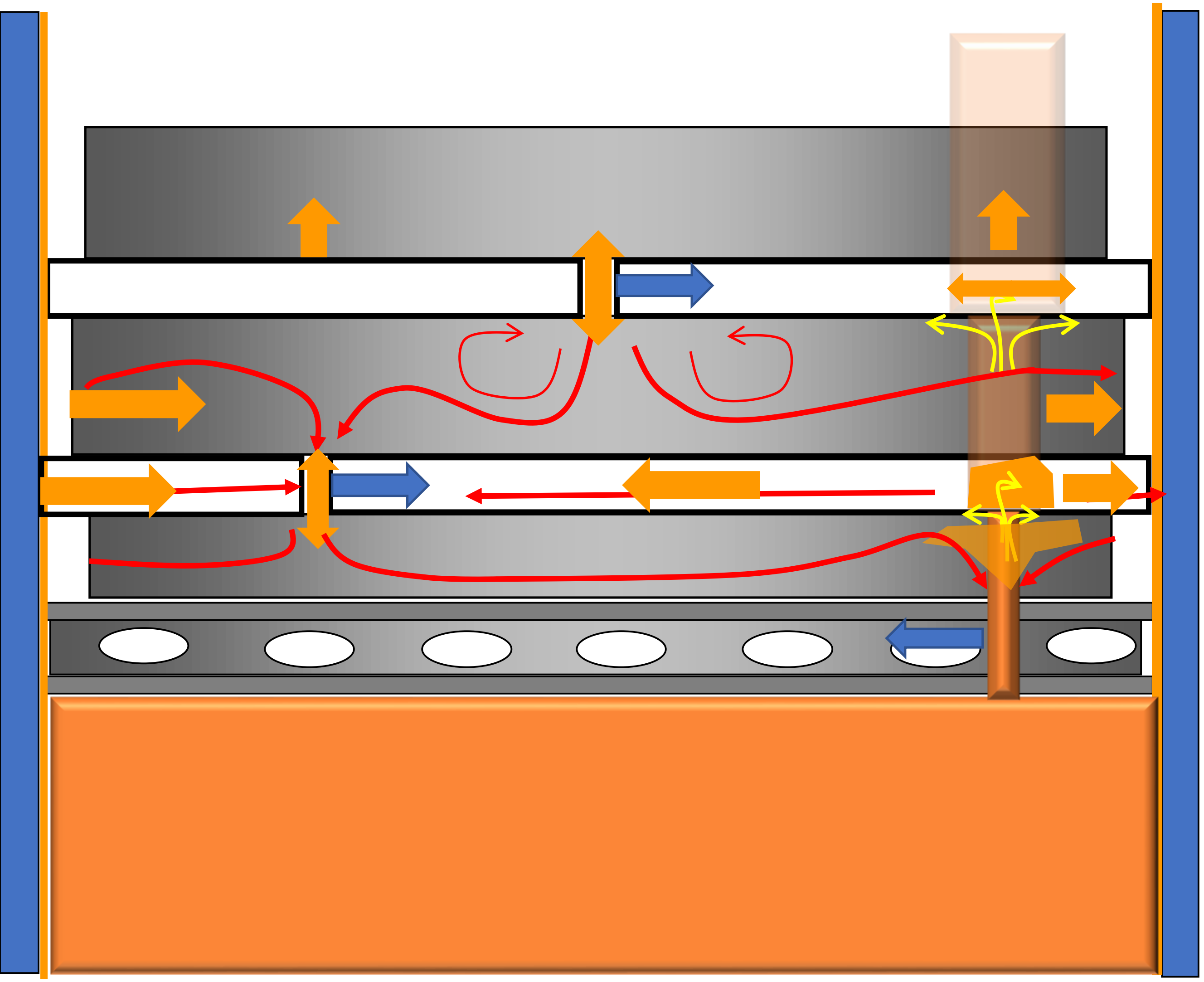
- oil supply to ring lower flank lubrication
- TDC bridging in exhaust stroke (source for up-scraping in compression stroke)
- Enhanced bridging compression and expansion (not observed yet)

Conditions Scraping most likely occurs

- Expansion stroke due to conformability difference of top and 2nd rings
- 2nd ring gap is close

Oil accumulation pattern below the top ring gap may stay for a long time after the top ring gap moves away from the OCR gap – observed from LIF





Conclusions:

1. A healthy system is needed for the power cylinder unit (PCU) to survive the harsh environment and to maintain proper lube oil consumption and blowby over the engine life time.

2. Design of oil control ring and groove plays a critical role in both controlling the oil supply to the upper ring pack region and in releasing the oil to the crankcase.

3. For the first time, it was observed that the oil can be spread to the top of the liner helping build tribo-layer in that region, through the supply from the TLOCR gap and rotation of the rings.

4. If the system can survive with the sole oil supply from the TLOCR gap, it represents the theoretical limit of the Lube oil consumption of PCU. The ability to predict the LOC and oil spreading rate to the dry region with this limit is useful in designs and formulations of the particle filter and lubricant additives, respectively.