Optical Surface Analyzer LSA

Retention Force Balance (RFB) Module

Fig. 1 LSA100 with RFB module installed

The study of the behavior of liquid drops on solid surfaces has been an important subject, because of both its scientific interest and its implication in industrial applications, including wetting, dyeing, spraying, cleaning, cooling, tribology, micro-fluidics, etc. However, the mechanics of the drop while it is still in its static state, just before motion starts and during its motion, are still far from being well-understood.

When a liquid drop on a solid surface is subjected to a force (e.g. gravitational force or centrifugal force) which acts to slide it relative to the solid surface, there appears, due to adhesion, a lateral retention force that opposes the motion. Before the acting force reaches a critical limit and an actuated drop begins finally to move, the shape of drop changes gradually with the force increasingly applied such that the forces acting at the triple-phase contact line balance the actuation forces. These (contact line) forces are governed by the contact angles along the contact line and interfacial tensions involved between triple phases, and are called “lateral retention force”. This retention force is, given other conditions, not only closely related to the morphology of the triple-phase contact line and the distribution of contact angles alone the contact line, but also dependent of the normal force the drop exerts on the solid surface.

Traditionally, the tilting stage method (Fig. 2) is widely employed for studying the retention force. By placing a drop of a certain size on a horizontal solid surface and tilting the latter at a controlled speed smoothly, the change of contact angles and triple-phase contact line positions at the front and back side is followed (Ref. to Fig. 2), until the drop starts to slide (or roll) and moves out of the camera’s field of view, or the maximum tilting angle (mostly 90 degrees) is reached.

The main limitations of the tilting stage method are:

1) The normal force (or acceleration), ***mg cos(α)***, exerted by the drop on the surface varies with tilting angle ***α***: from its maximum value (= the weight of drop ***mg***) at 0 degree to extinction at 90 degrees.
2) The maximum force that can act on the drop to bring it into motion alone the surface is limited to the weight of the drop itself, and by changing its weight (via size) in order to modify this driving force, the normal force mentioned in 1) varies inherently.

These restrictions make it difficulty, to study the relationship of retention force to the contact angles and to the resting time (after drop deposition on the surface), isolated from its dependence on the normal force. The second constraint limits the applicability of the tilting stage method, in most cases, only to hydrophobic systems, i.e. to low retention force systems, where a liquid drop of a reasonable size will start eventually to move driven by its own weight as the tilting goes to its maximum extent.

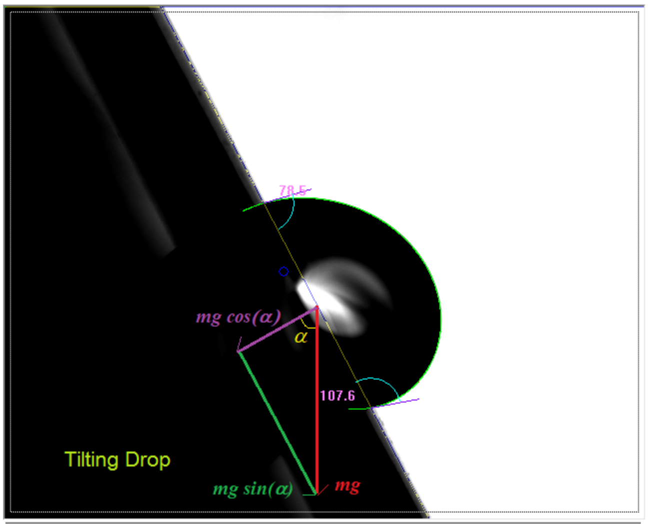

Fig. 2 Tilting Stage method: tilting angle = ***α***, normal force = ***mg cos(α)***, driving force = ***mg sin(α)***

Recently a new method has been introduced (cf. R. Tadmor et al.), which is based on the centrifugal force to drive a drop on a rotating solid surface to move. This new method allows for decoupling of lateral and normal forces the drop experiences. Furthermore, the lateral driving force (or acceleration) can be increased to a much higher value (e.g. 40g) than 1g as in case of the tilting stage methodology, and the normal force may be varied but kept constant during the experiment.

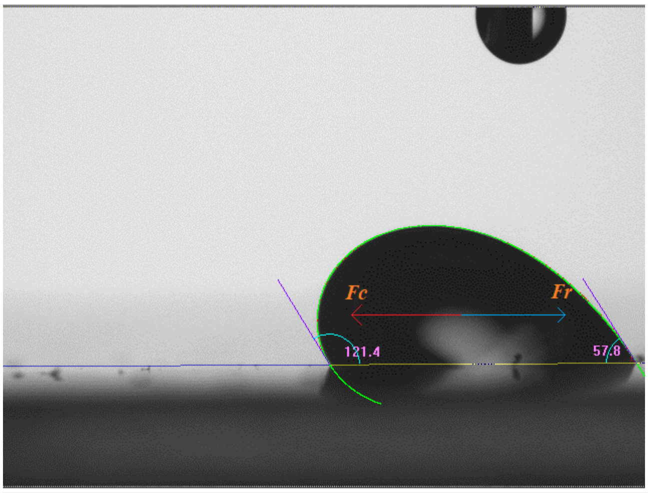

Fig. 3 Retention Force Balance RFB: *Fc* = centrifugal force; *Fr* = retention force

Based on this new principle, a new module, Retention Force Balance (RFB), has been introduced into the LSA100/200-series (Fig. 1). A drop of a given volume is placed on a sample surface fixed on a motor driven turntable. Subsequently the turntable is started to rotate, whose speed can be controlled and measured precisely. The drop experiences a centrifugal force (driving force, ***Fc*** in Fig. 3) which tries to drive it away from the center of rotation and grows with increasing rotation speed. Like in the case of tilting stage, the shape of drop changes increasingly (Ref to Fig. 4) with the driving force such that the force acting at the triple-phase contact line (***Fr*** in Fig. 3) balances the actuation force. As soon as a certain critical rotation speed is reached, and hence the corresponding centrifugal force, the triple-phase contact line starts to creep or move, most likely locally at some sites at the beginning, followed by a “global” sliding movement – the drop slides away from the center of rotation.

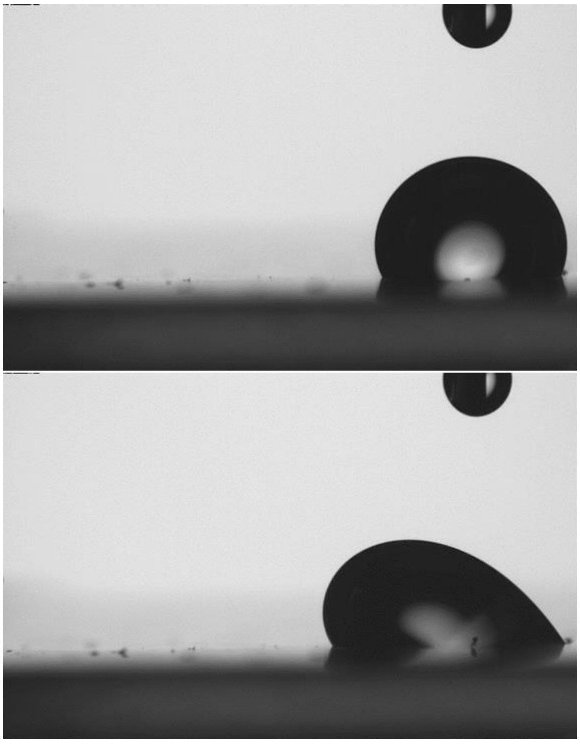

Fig. 4 A drop on RFB: before rotation started (top) and after the rotation speed was increased to a certain value (bottom)

From the drop images recorded during this process, the change of contact angles and of triple phase contact location at the front (advancing) and back (receding) side in dependence of the driving force can be determined, as well as the critical centrifugal force which is reached as the drop as whole begins to slide (move). Thereby, among others, the values of advancing and receding contact angles (incl. their maximum values) and the maximum retention force, which corresponds to the maximum driving force that is required to move the drop, can be determined (ref. to Fig. 3 and 5).

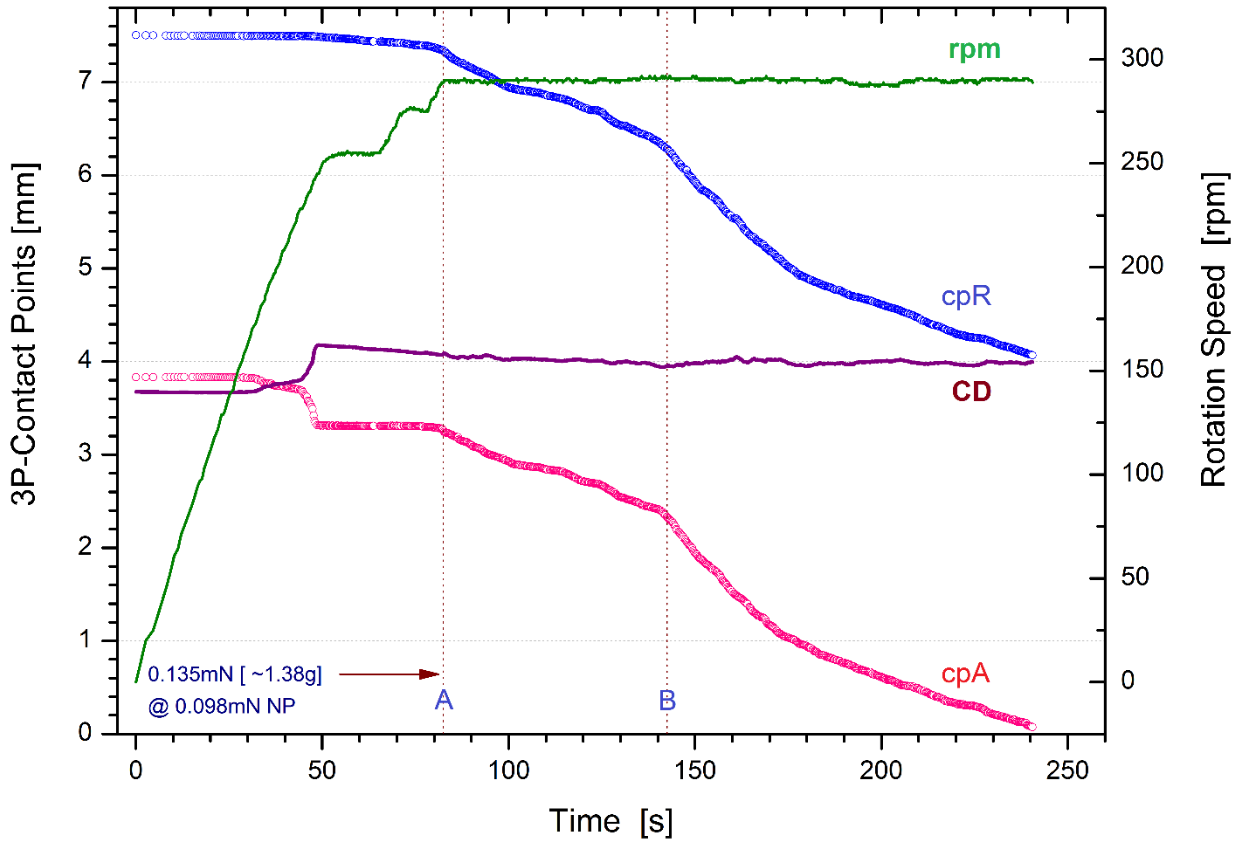

Fig. 5 A water drop (10ul, 15mm to RC) on RFB: Dependence of triple contact line position at front (cpA) and back (cpR) side and drop contact diameter (CD) on the rotation speed (rpm). Point A marks the moment the drop started to move as whole, from the momentary rotation speed the corresponding driving force was computed, which correlates with the maximum retention force 135µN

Working with an RFB module is simple, and is in no way more cumbersome than a tilting stage measurement. The included software module provide user with a straightforward GUI (ref. Fig. 6) to perform the measurement and subsequent computation.

RFB can be fitted with a SideView- or TopView-camera alone, or both cameras simultaneously. In the latter case, not only the contact angles and their variation with increasing driving force can be determined, but also the details of the contact line morphology and its variation, which is critical as well for establishing a reasonable correlation between contact angles and retention force. Furthermore, RFB module can be equipped with temperature/humidity chamber, for carrying out experiment under well-controlled ambient conditions.

RFB module can be used for studying

- Retention force of liquid drops on solid surfaces and its dependence on the normal force, drop size, triple contact line morphology, resting time, temperature, humidity, etc.;
- Dynamic contact angles incl. dynamic/maximum advancing/receding contact angles;
- Sliding/creeping behavior of drops incl. the related speed;

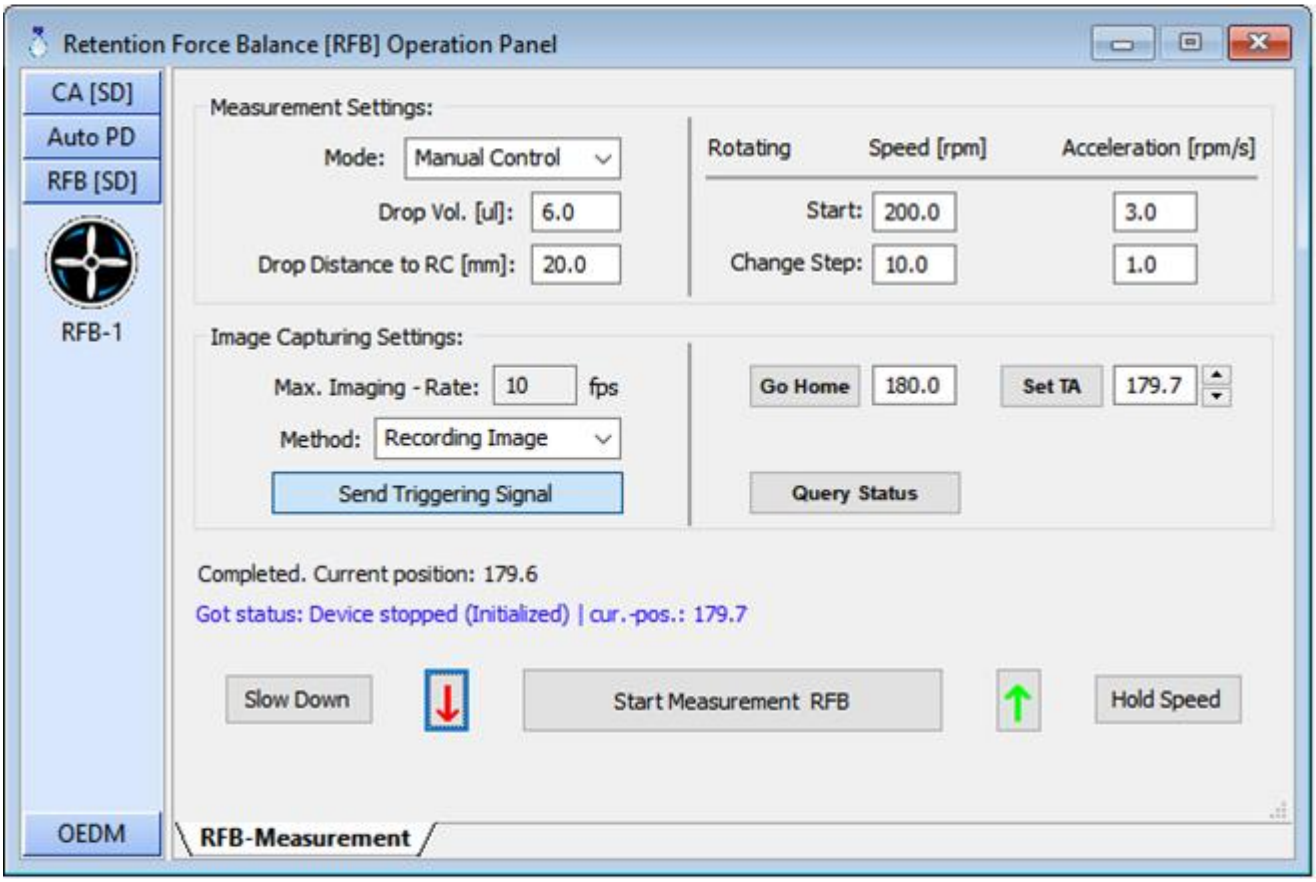

Fig. 6 Software control panel for working with RFB

Technical Data (RFB 20):

Rotation Table diameter: 160mm
Rotation Speed: Range 0-800RPM; Resolution: 2RPM; Acceleration: 1-100rpm/s.
Max. centrifugal force (corresponding acceleration): ≥40g
Package includes: Rotation table module, adapter for montage, controller box, connection cables and software module.