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MINI TRACTION MACHINE FOR LUBRICANT EVALUATION

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ABSTRACT

This article provides a practical overview of several commonly used tribological testers and highlights how each device contributes to understanding lubricant behaviour. The focus is placed on the Mini Traction Machine (MTM), which allows independent control of rolling and sliding to simulate conditions found in gears and rolling contacts. Through measurements such as traction coefficient, slide-to-roll ratio, and optional in-situ film thickness, the MTM offers clear insight into lubrication regime transitions and additive performance. For context, the capabilities of the Four-Ball and Pin-on-Disc testers are also introduced, outlining how they evaluate wear, friction, and extreme-pressure characteristics. Overall, this sharing session aims to help researchers and engineers select suitable test equipment and better interpret tribological responses under different operating conditions.

KEYWORD

Tribology, Lubrication testing, Mini Traction Machine (MTM)

MINI TRACTION MACHINE (MTM)

The Mini Traction Machine is a specialized ball-on-disc tribometer that uniquely allows independent control of rolling and sliding motion between the contact surfaces. In the MTM, a steel ball is loaded against a rotating steel disc (often in a lubricant bath). Crucially, both the ball and the disc are driven by separate motors, so one can impose a specific slide-to-roll ratio (SRR): this is the percentage of sliding relative to the mean rolling speed. By adjusting the disc and ball speeds, the MTM can create conditions from pure rolling (zero SRR) to pure sliding, as well as any mix in between [1]. The average surface speed of the two (entrainment speed) and the SRR together determine the lubrication regime in the contact. The contact itself is typically a point or very small elliptical contact (like a ball-on-flat in elastic contact, akin to a miniature rolling bearing contact). Because the ball and disc can be run in the same direction or in opposite directions (contra-rotation), the MTM can achieve scenarios like a high sliding speed but low entrainment speed, which is particularly useful for testing scuffing or micro-pitting resistance of lubricants and surface coatings

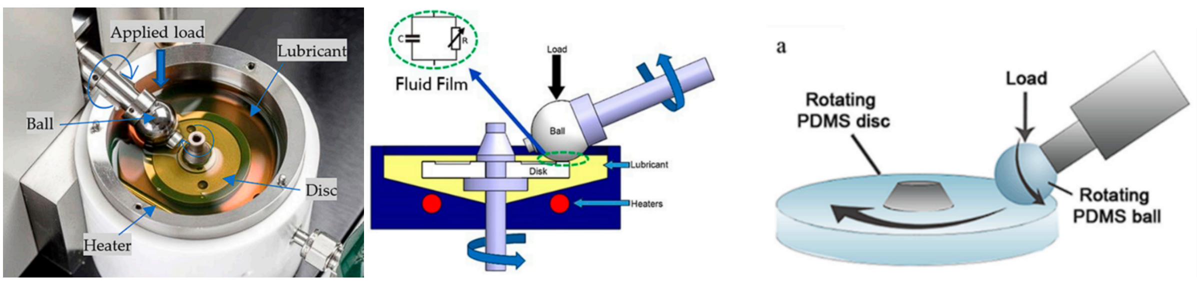

Figure 1: Schematic diagram of the mini traction machine (MTM) [2,3,5].

Three SRR defined as in Equation (1), where u_d is the disc speed and u_b is the ball speed at the contact between the disc and the ball. Controlling the SRR will allow for the simulation of rolling and sliding contacts, such as gears or roller elements, as shown in Table 1. As shown in Figure 1, the lubricant forms a film between the ball and disc. Electrically, the film will have some impedance, which is dictated by the film thickness and electrical resistivity of the fluid.

$$SRR = \left(u_d - u_b \frac{u_d - u_b}{2}\right) \quad (1)$$

$$SRR\ (\%) = \left(\frac{u_b - u_d}{2(u_b - u_d)}\right) \times 100 \quad (2)$$

Table 1: SRR Interpretation Table (MTM).

SRR (%)	Kinematic condition	What physically happens	Notes for MTM users
0	Pure rolling	Ball and disc have identical surface speeds; no relative sliding	Used to measure *rolling traction* and baseline EHL losses.
>0 to 5	Near-pure rolling (very low slip)	Mild differential speed; almost all motion is rolling	Sensitive to surface finish and lubricant rheology.
5 to 10	Low mixed rolling–sliding	Onset of microslip within the contact	Often where friction rises sharply in traction curves.
10 to 30	Rolling–sliding (mixed regime)	Significant slip with rolling still present	Common window for traction measurements and Stribeck mapping.
30 to 50	Sliding-dominated rolling	Sliding is dominant, rolling component small	Boundary effects become increasingly important.
≈50	Transitional practical limit	One surface may approach zero speed	Many MTM studies avoid >50% for stability/repeatability.
>50	Extreme slip	Physical meaning degrades	Not recommended; contact behavior no longer representative.
100	Theoretical pure sliding (special case)	Disc stationary, ball moving (or vice-versa)	MTM normally does not operate in this mode; use a dedicated sliding tribometer instead.

MEASURED PARAMETERS

The primary output of the Mini Traction Machine (MTM) is the traction coefficient, which represents friction under rolling–sliding conditions and is measured via a force transducer that detects frictional torque at the ball–disc interface. By varying operating conditions, traction curves (friction versus slide-to-roll ratio) and Stribeck curves (friction versus entrainment speed or Hersey number) are generated, enabling evaluation of lubrication behaviour across boundary, mixed, and elastohydrodynamic regimes [2], as shown in Table 2. When fitted with optical interferometry (SLIM), the MTM can also measure lubricant film thickness in real time using a coated glass disc, allowing direct observation of nanoscale film formation and tribofilm growth during operation [3], as shown in Figure 2. The combination of friction and film measurements provides insight into lubrication regime transitions and additive performance, while temperature and load control enable testing under conditions relevant to practical mechanical applications [4].

Table 2: Parameter measure in mini traction machine.

Category	**Parameter**	**Symbol**	**Unit**	**What it represents**	**Why it matters**
Traction behaviour	Traction / friction coefficient	μ	–	Ratio of traction force to normal load	Quantifies rolling–sliding friction under EHL and boundary regimes
Kinematics	Slide-to-roll ratio	SRR	%	Degree of slip between ball and disc	Distinguishes pure rolling from mixed and sliding motion
Motion control	Ball speed	u_b	m s^{-1}	Surface velocity of the ball	Affects lubricant entrainment and shear rate
Motion control	Disc speed	u_d	m s^{-1}	Surface velocity of the disc	Enables differential speed to generate SRR
Film formation	Entrainment speed	u_e	m s^{-1}	Mean of ball and disc speeds	Governs elastohydrodynamic film thickness
Load	Normal load	W	N	Applied contact load	Controls contact pressure and regime transition
Contact condition	Contact pressure (Hertzian)	p_0	GPa	Max theoretical pressure at contact	Determines risk of starvation, wear, and additive activation
Thermal condition	Bulk oil temperature	T	°C	Test temperature	Controls viscosity, reaction kinetics, and tribofilm growth
Electrical	Contact resistance (if enabled)	CR	Ω	Electrical impedance across contact	Used to infer lubricant film presence
Surface condition	Ball roughness	Ra_b	μm	Initial ball surface finish	Affects asperity contact and boundary friction
Surface condition	Disc roughness	Ra_d	μm	Initial disc surface finish	Influences lubricating film stability
Test condition	Time	t	s or min	Test duration	Used to assess running-in behaviour and stability
Derived (optional)	Central film thickness	h_c	nm	Lubricant film at contact centre	Indicates lubrication regime
Derived (optional)	Lambda ratio	λ	–	Film thickness / roughness ratio	Classifies boundary vs mixed vs EHL regime

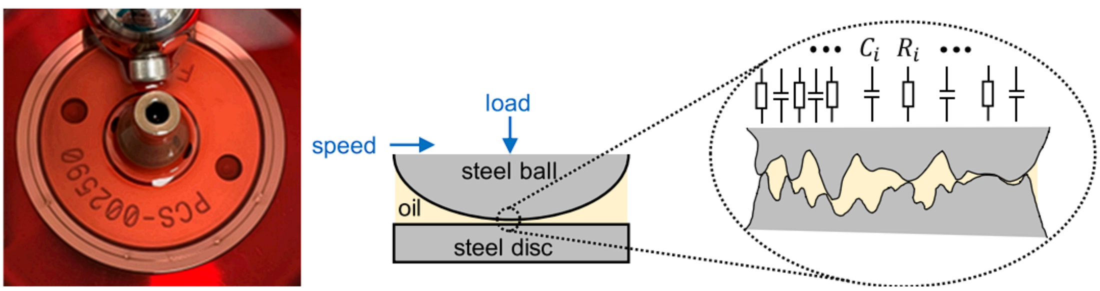

Figure 2: Illustration of parallel resistors (Ri) and capacitors (Ci) in a steel ball-on-steel disc contact under mixed lubrication regime [2,4].

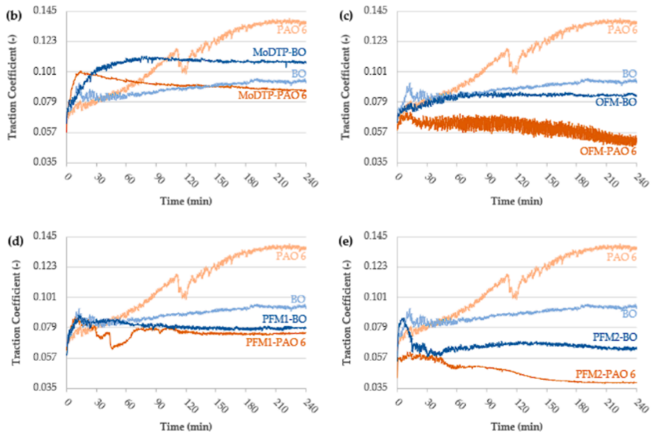

Figure 3: Traction coefficient of MTM [5]

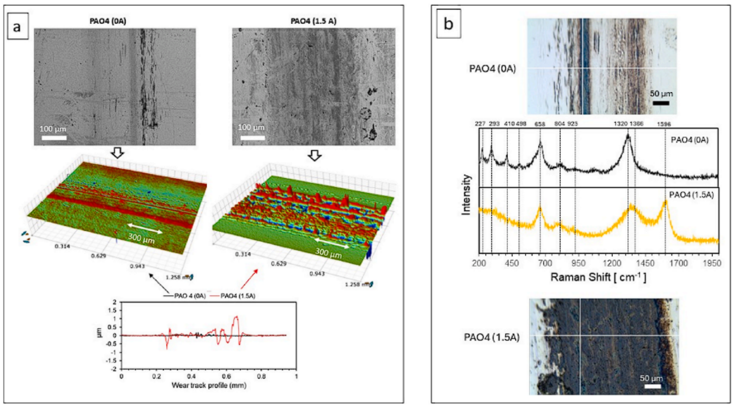

Figure 4: Comparison of wear characteristics of the wear tracks generated on the disc samples by non-electrified and electrified MTM tests using neat PAO4: (a) SEM, and 3D/2D profiles; (b) Raman spectra [1].

ADVANTAGES OF MTM

The MTM offers several unique advantages that make it a powerful tool, especially for modern lubricant development:

Full Traction Mapping

It provides comprehensive data on frictional behavior across regimes. Engineers can directly obtain a lubricant's Stribeck curve critical for understanding how a new low-viscosity oil will behave from idle to high-speed conditions [5], as shown in Figure 3. This is vital in automotive applications targeting fuel economy, where oils are becoming thinner: the MTM can confirm that an ultra-low viscosity 0W-8 oil still maintains an EHL film at high speeds while also examining its boundary friction at low speeds.

Film Formation Monitoring

With accessories like the SLIM, the MTM can measure the formation of nanometer-scale tribofilms (such as anti-wear additive films) in real time [1], as shown in Figure 4. This is enormously valuable for research on additive chemistry – for example, determining how quickly a new ashless anti-wear additive forms a protective film, or comparing the film thickness of ZDDP vs. an organic sulfur/phosphorus under identical cycles. No other standard tribometer in this comparison directly measures film thickness; this capability has made the MTM an industry standard for studying boundary film-forming additives [3].

Simulation of Real Contact Mechanics

The MTM's ball-on-disc configuration with rolling + sliding is directly relevant to rolling element bearings, gears, and cam-follower pairs [2]. For instance, automotive gear oils are evaluated on MTM to measure friction (traction) at various slide-roll ratios, since gear teeth experience ~20–40% SRR in mesh. The measured traction coefficient correlates with efficiency losses in a gearbox. Similarly, grease or oil for a bearing can be tested: how much friction (and heat) will it generate under loaded rolling motion? The MTM can rank lubricants by their EHL friction coefficient in a way four-ball or pin-on-disc cannot.

Scuffing and Wear Testing under Control

While the MTM is not primarily a wear tester, it has been used to perform controlled scuffing tests by running at high SRR and load until failure. The advantage is one can approach scuffing in a controlled manner and detect the onset via friction spikes [4]. This controlled method is more efficient than full-scale gear tests for screening lubricant scuffing resistance.

Relevance to Emerging Applications

In context of hydrogen-fueled engines, one potential issue is that the combustion of hydrogen produces water and yields very little lubricating by-products (unlike gasoline which leaves some residues that might aid lubrication slightly). Oils in a hydrogen engine may face more moisture and thinner films. The MTM can be used to evaluate candidate lubricants for such engines by seeing how they perform at very low viscosity or with water contamination. While not many public studies are yet available, the MTM's ability to test under different loads and track friction in boundary regime could help design oils that mitigate hydrogen's impact (for example, ensuring boundary additives activate quickly if water disrupts the film). For biolubricants, MTM tests have highlighted their high viscosity index and strong film-forming at elevated temperatures – e.g. vegetable-based oils often maintain thicker EHL films at high temperature compared to mineral oils [6]. This means an MTM can show that a bio-oil still lubricates hydrodynamically at temperatures where a mineral oil's film might thin out too much. Moreover, any naturally polar oil might create distinct traction behavior; researchers indeed use the MTM to measure how bio-oils can lead to lower friction in mixed lubrication due to robust boundary films

COMPARATIVE SUMMARY OF TESTERS

To crystallize the differences among the four tribotesters discussed, Table 1 presents a side-by-side comparison of their key features, operating conditions, and typical use cases.

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