Comparison of On-road & Laboratory-based Rolling Resistance Measurements

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Tire Meets Science

11-12 September 2013, Aachen, Germany

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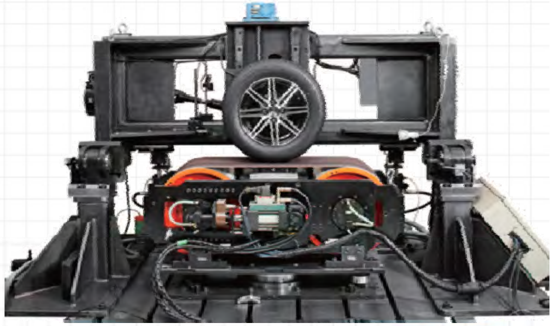
- Objective
- On-Road Measurement
- On-Road Results
- In Door Testing
- In Door Results and Comparison
- Summary

Objectives

1. Comparison of on-road rolling resistance measurements with standardized indoor testing

2. Comparison of standardized testing on flat-belt and drum machines



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On-Road Rolling Resistance Measurements

Coast-down method

e.g. VTI, Sweden [9, 12]

Instrumented trailer

**e.g. FKFS, Germany,
BASt, Germany,
HUT, Finland [6]**

Instrumented vehicle

e.g. A&D, Japan

On-road Measurements

Test Vehicle:

- Instrumented Mini Cooper S
- Proving ground in Tochigi, Japan

Test Tires:

- Rear left(RL) & rear right(RR)
- Bridgestone Sneaker2 (205/55 R16 91V)
- 250 kPa (capped)

Test Procedure:

- Round course 6 repeats at different speeds
- Selection of straight, constant speed phase for data analysis

Vehicle Instrumentation I

A&D Wheel force Sensor (WFS)

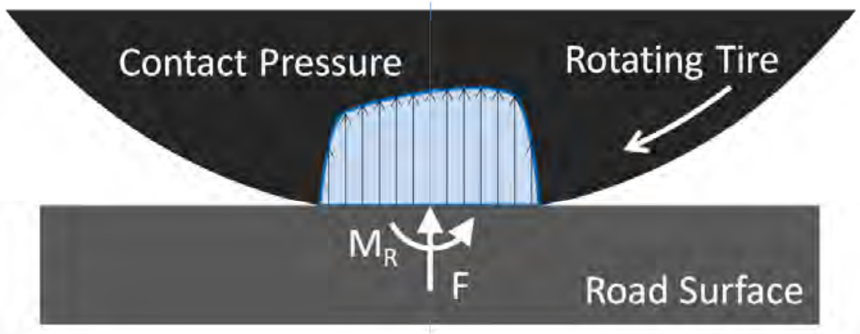
- Unique design
- Distributed force bridges with model based decomposition to get orthogonal force components
- low cross sensitivity
- low temperature sensitivity
- high sampling rate
- High Accuracy
  0.1% resolution
  (6N or 1.8Nm)

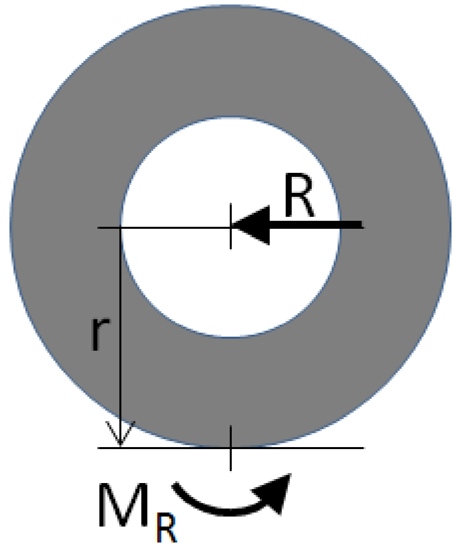
Vehicle Instrumentation II

- Doppler Velocity Sensor
  - Vehicle velocity
- GPS Sensor & In-vehicle Network
  - vehicle longitude, latitude, altitude, and ECU CAN communication
- A&D Wheel Position Sensor
  - 6 degrees of freedom of the tire relative to chassies
- Inertial Sensor
  - vehicle roll, pitch and yaw
- Digital Signal Processing & Acquisition
  - 100Hz sampling of all signals

Tire Rolling Resistance

- Rolling resistance is created in the Tire patch
  - Tire Patch shows an asymmetric Pressure distribution, which can be substituted by:
    - a total contact force F and
    - a moment M_R
  - M_R appears as resistance force R on the wheel hub
    $M_R = R \cdot r$
    r: dynamic rolling radius





Mathematical Formulation

$$M_R = R \cdot r \qquad [1]$$

Torque equation: $J \cdot \dot{\omega} = - My - MR + FA \cdot r$

with [1]: $J \cdot \dot{\omega} = - My - R \cdot r + FA \cdot r \qquad [2]$

Force equation: $m \cdot a = Fx - FA$

$\Rightarrow \quad FA = Fx - m \cdot a \qquad [3]$

Kinematic condition: $v = \omega \cdot r$

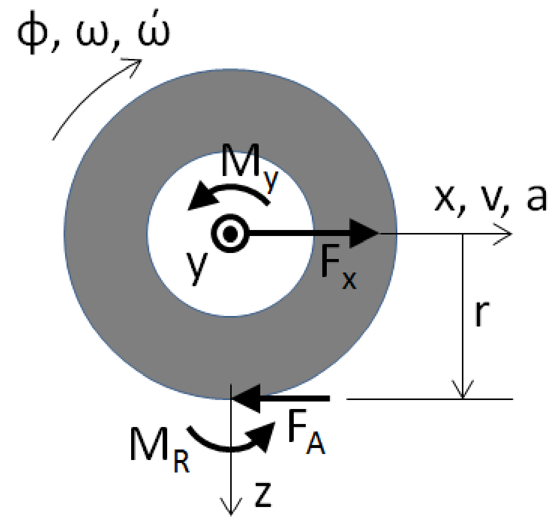
$\Rightarrow \quad r = v / \omega \qquad [4]$

[3] in [2]: $J \cdot \dot{\omega} = - My - R \cdot r + (Fx - m \cdot a) \cdot r$

$\Rightarrow \quad R = Fx - m \cdot a - (1 / r) \cdot (J \cdot \dot{\omega} + My)$

with [4]: $\mathbf{R = Fx - m \cdot a - (\omega / v) \cdot (J \cdot \dot{\omega} + My)}$

Determined before the Experiment



r: Rolling radius

ϕ, ω, ώ: Angle, angular speed/ acceleration of wheel

x, v, a: Distance, speed, acceleration of wheel

J, m: torque inertia/mass of wheel

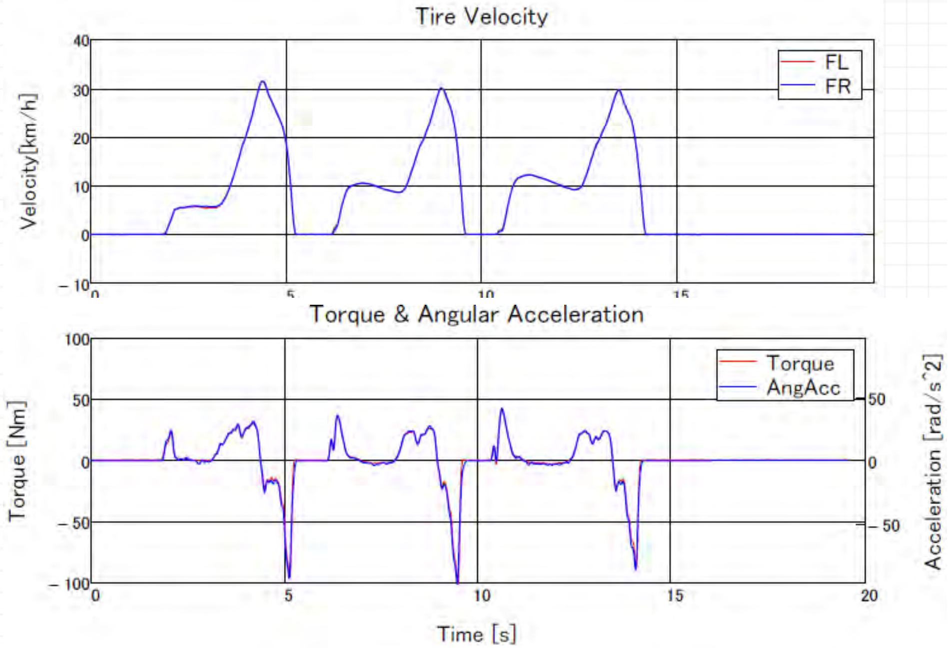
My ,Fx: Torque/force on wheel hub

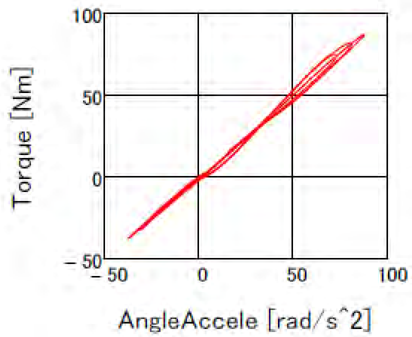
FA : Adhesive force

Parameter Determination

- Tire mass can be determined by lifting the wheel. WFS will show the mass
- Tire rolling inertia is determined using free load rotating wheel in acceleration and deceleration condition
- Measurement items
  - Tire angular speed ω [rad/s]
  - Angular acceleration $\dot{\omega}$ [rad/s^2]
  - Wheel torque My_{free} [Nm]
- Rolling inertia formula:

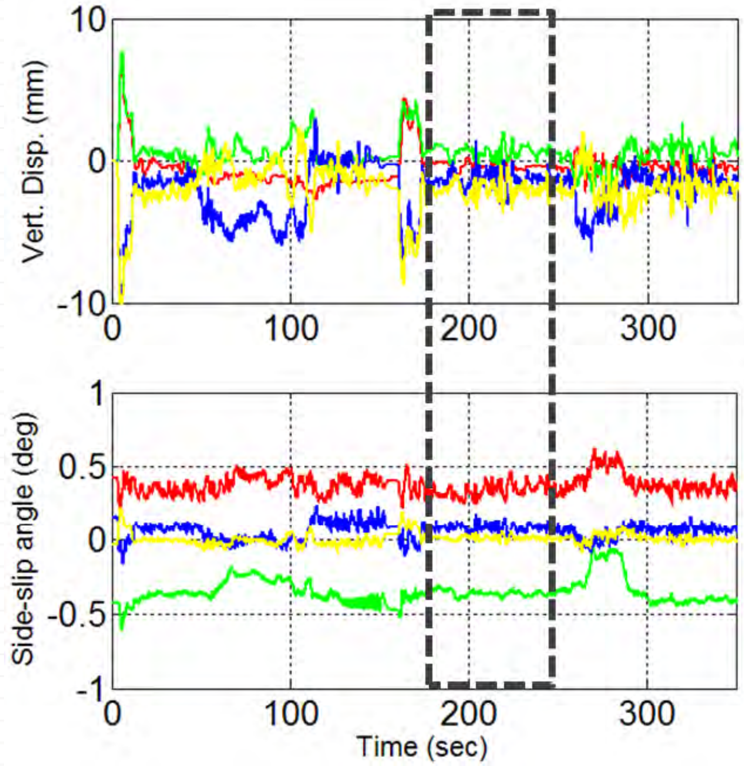
$$Jt = \frac{My_{free}}{\dot{\omega}}$$

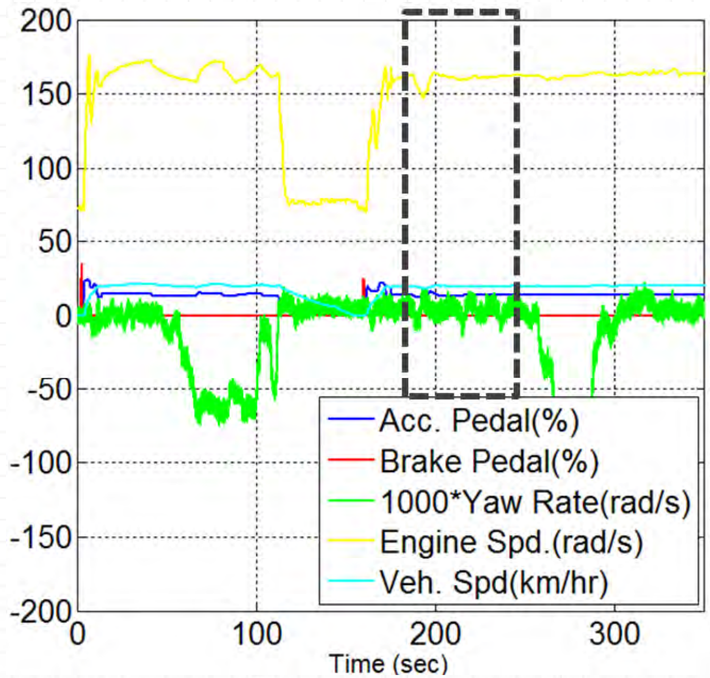




Data selection

- Data is filtered at 5Hz
- various signals are analyzed to find a time period having constant speed, straight line vehicle motion





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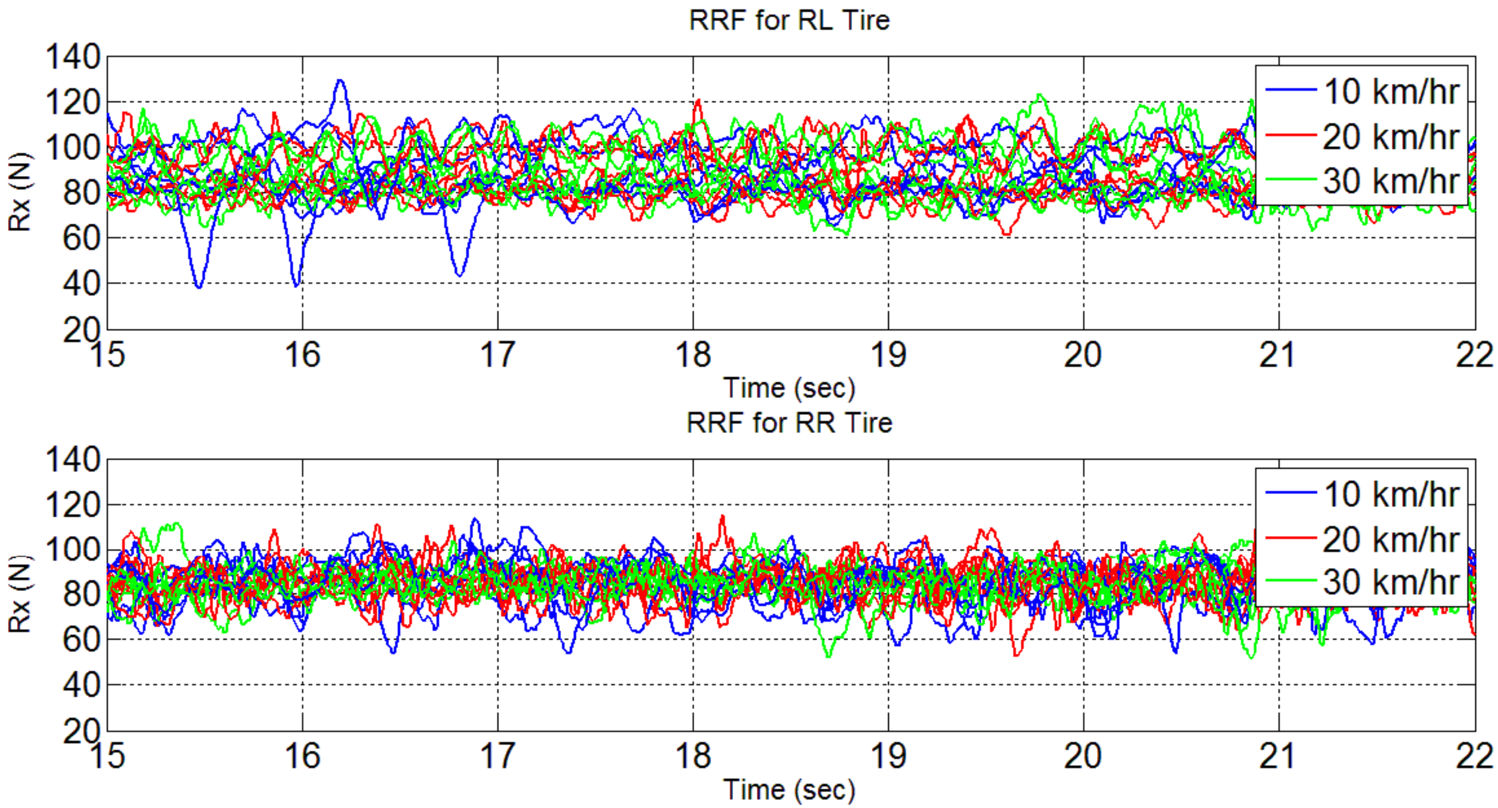
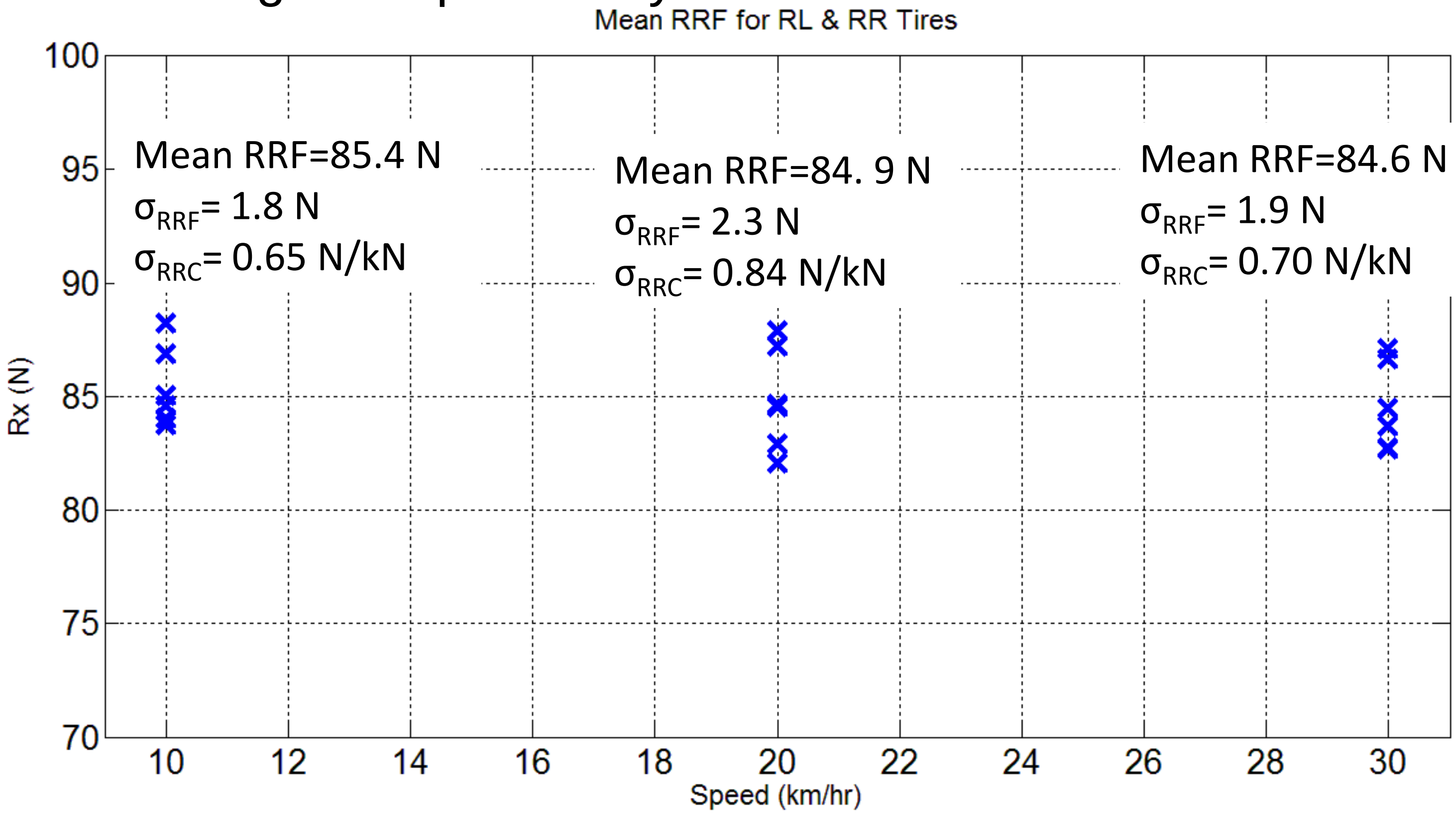
On-road Rolling Resistance Force

- Three speeds
- 6 tests for each speed
- Calculation applied to time data of Fx and My according to introduced formula



Mean Rolling Resistance Forces (RRF)

- Averaging the time record data for individual speeds
- Rolling resistance force does not vary with significantly with speed
- It is possible to have good repeatability for on-road measurements



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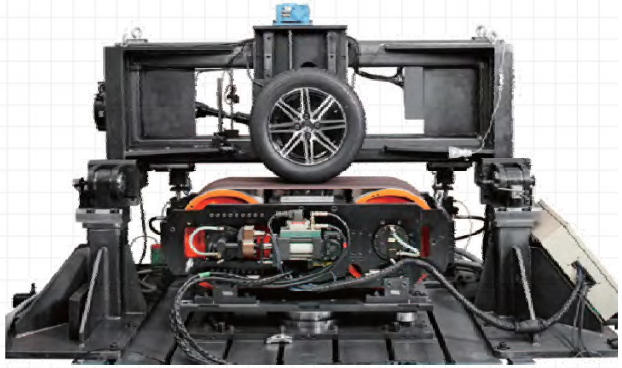
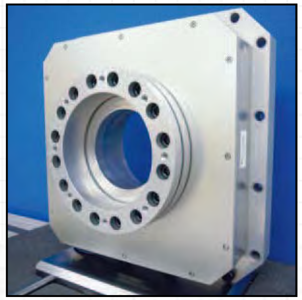
Indoor Testing Equipment

- A&D Standard Rolling resistance test rig
  - 2m Drum, Steel covered

- A&D Dynamic Flat Belt Test Rig
  - Steel Belt



- Force Measurement utilizing A&D Hub Sensor
  - MBS Sensor approach
  - Fx: 300N ±0.3N
  - Fz: 15kN ±20N
  - Machines Meet Reference Lab repeatability criteria



Test Procedure for Indoor Testing

Follow ISO28580 Test Procedure

- 3h thermal conditioning
- 30 min warm up
- Test conditions: Speed 80 km/h, 210kPa (capped), 80% max Load
- Skim Test at 150N

Measurements:

- Spindel Force
- Loaded Tire radius

Calculation of:

- Surface Force
- Parasitic Force
- Rolling resistance Force
- Temperature correction
- Rolling resistance Coefficient
- Curvature correction [3], [5]

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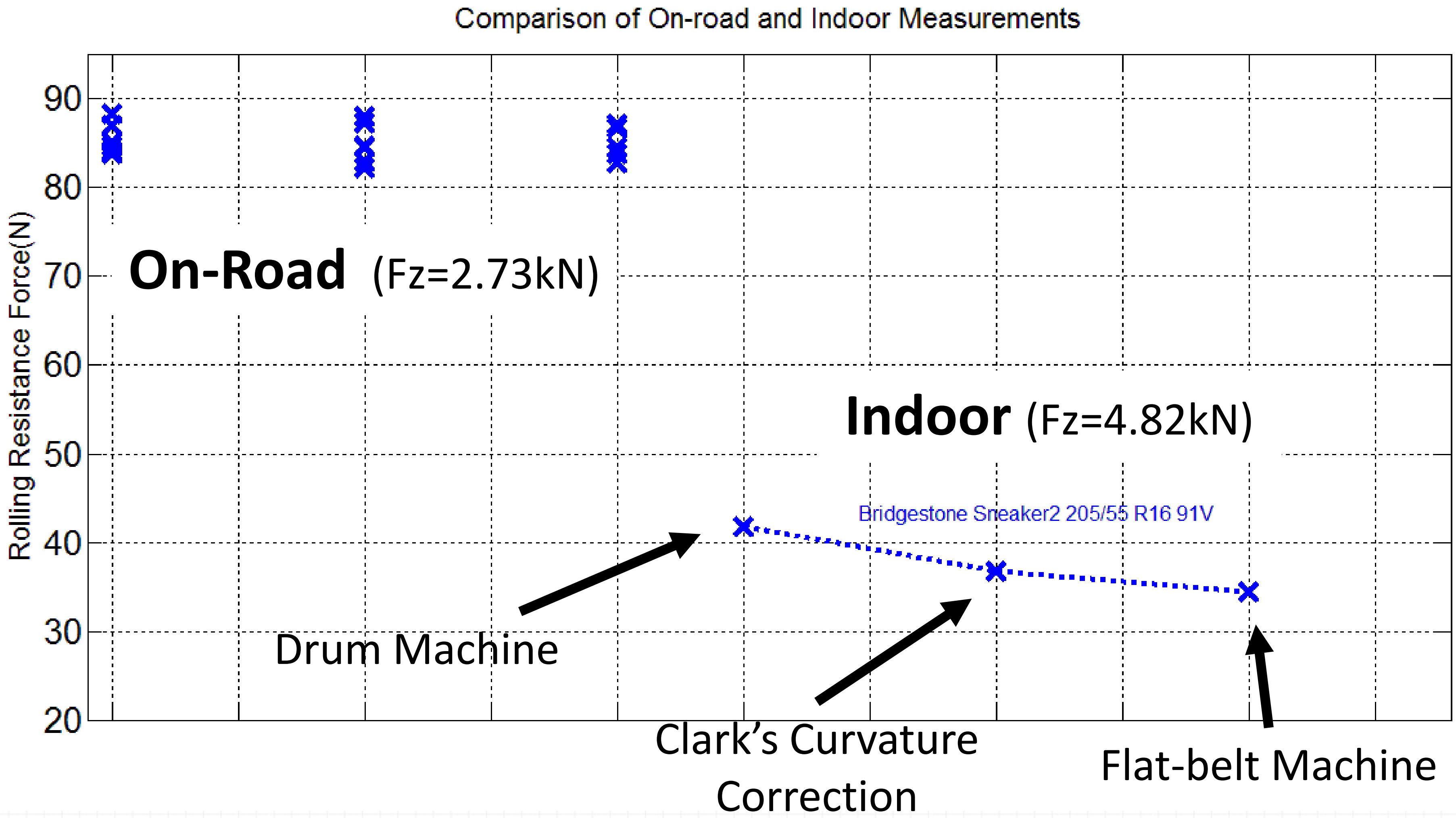
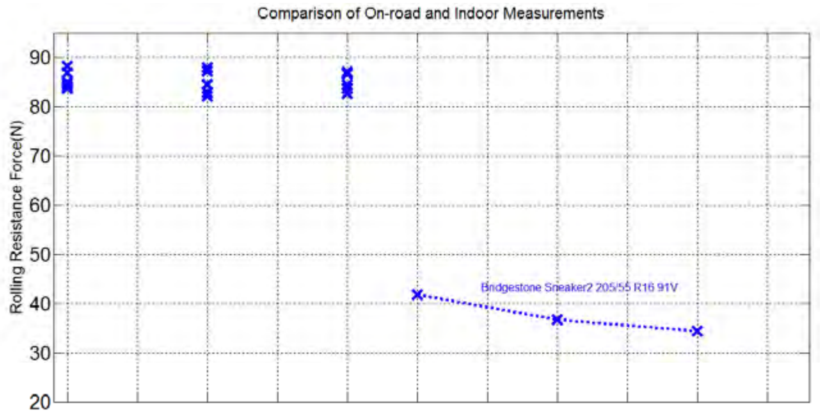
Comparison of Results

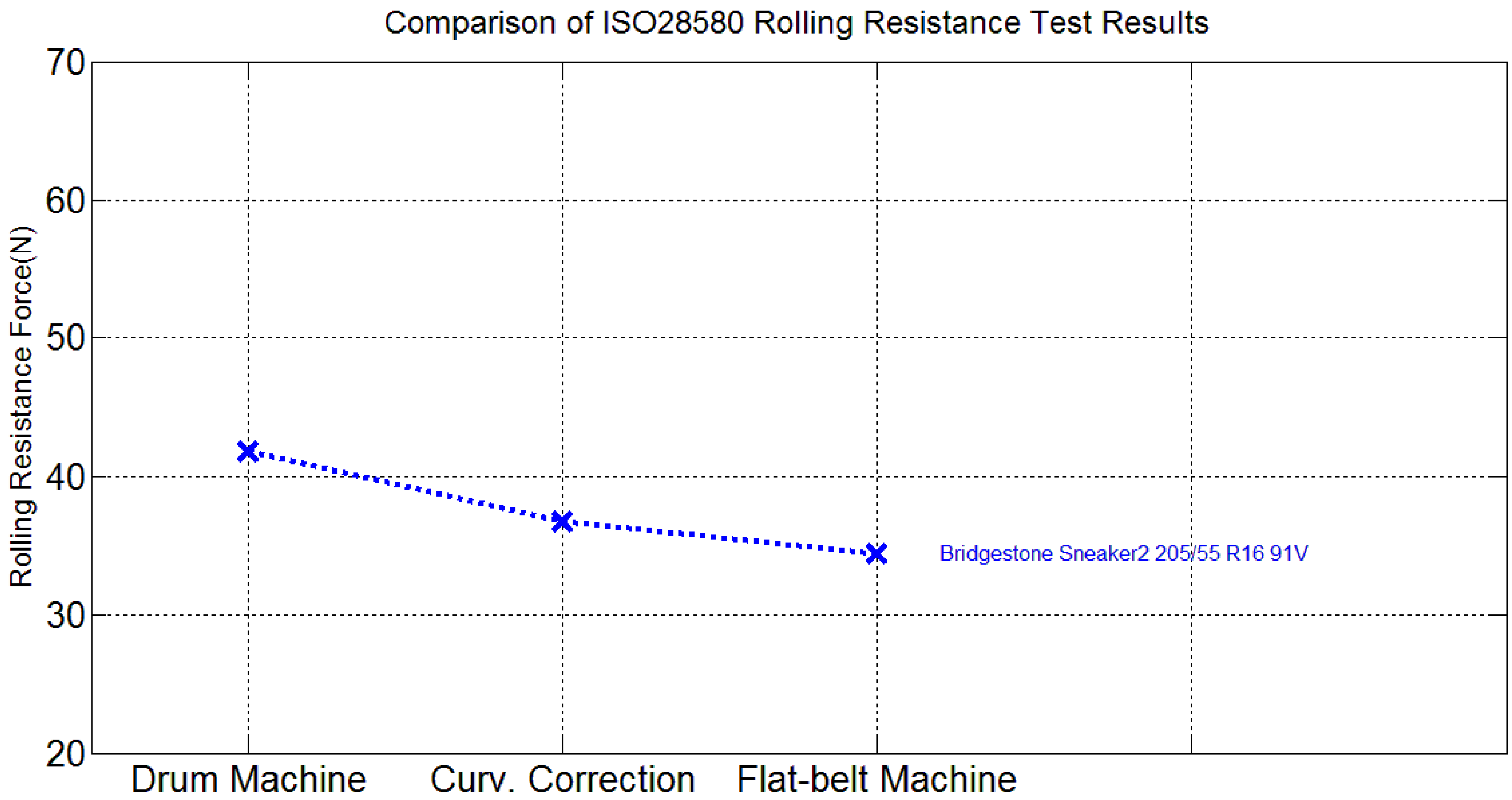


Potential Reasons for Differences

- Tire alignment (camber, toe) on the road [4]
- Roughness of road surface (unevenness, macrotexture) [7, 10-12]
    - Energy dissipation in the suspension
    - Dynamic vertical deflection of the tire leading to additional hysteresis
    - Additional friction losses due to microslip
- Uncontrolled environmental factors such as temperature and inflation pressure
- Measurement errors such as loaded tire radius

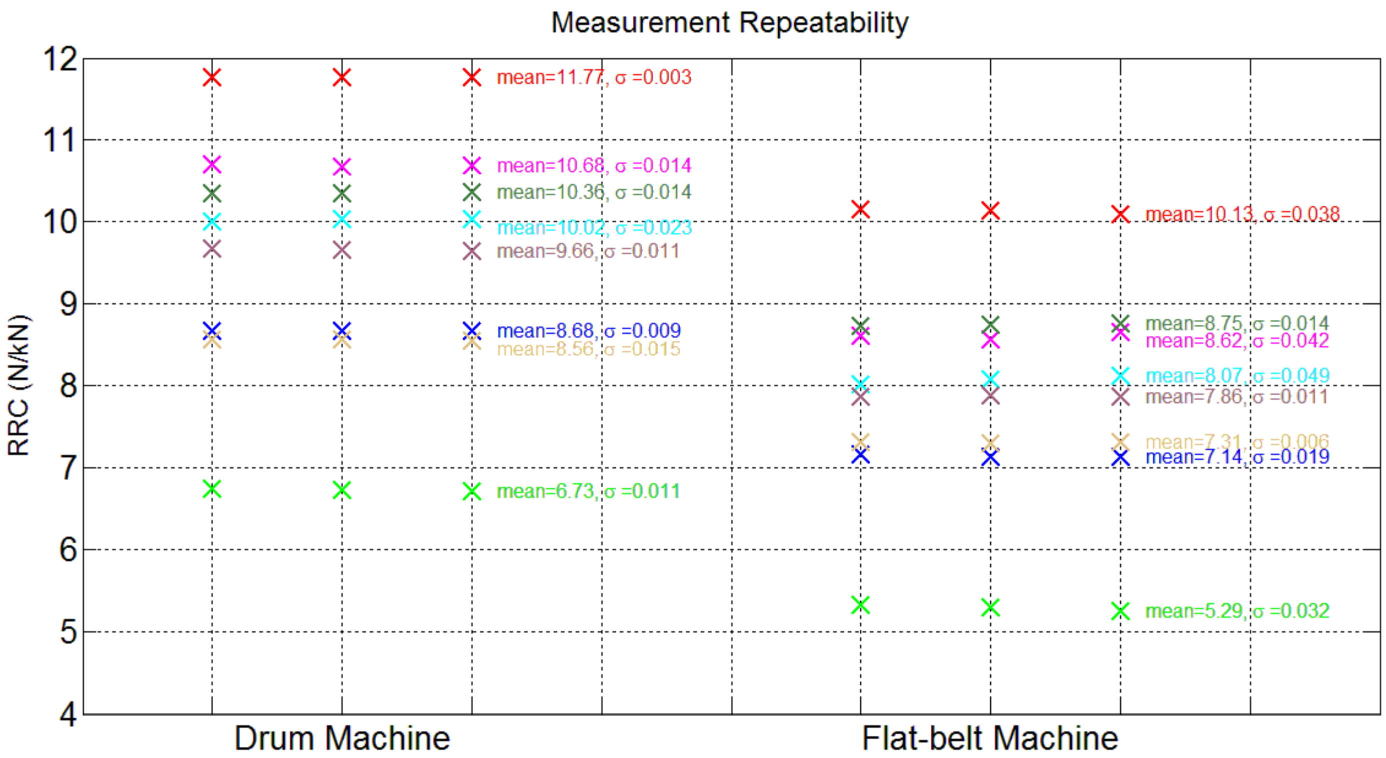


Indoor Testing Results



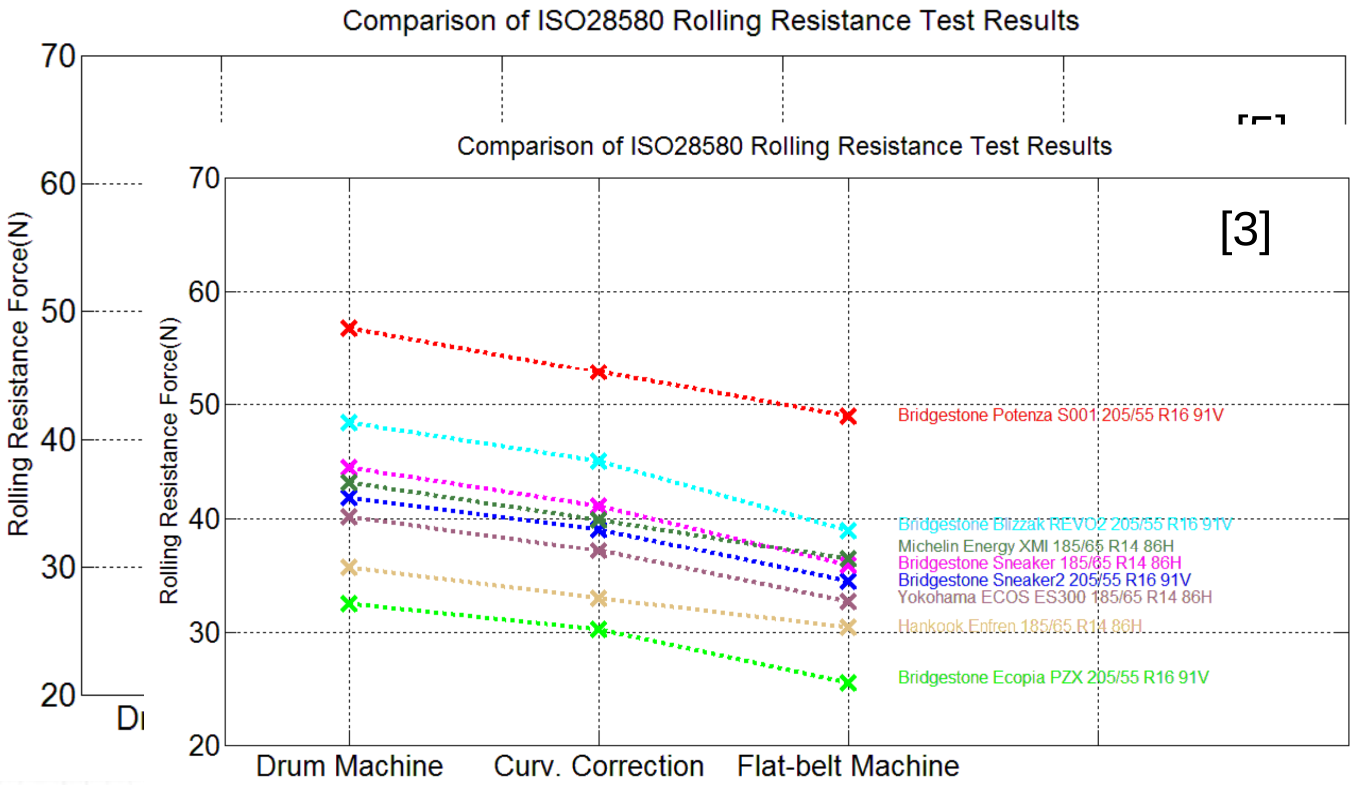
Repeatability Results

- Excellent repeatability is achieved for both drum & flat-belt machines
- Tire ranking is preserved during iterative testing



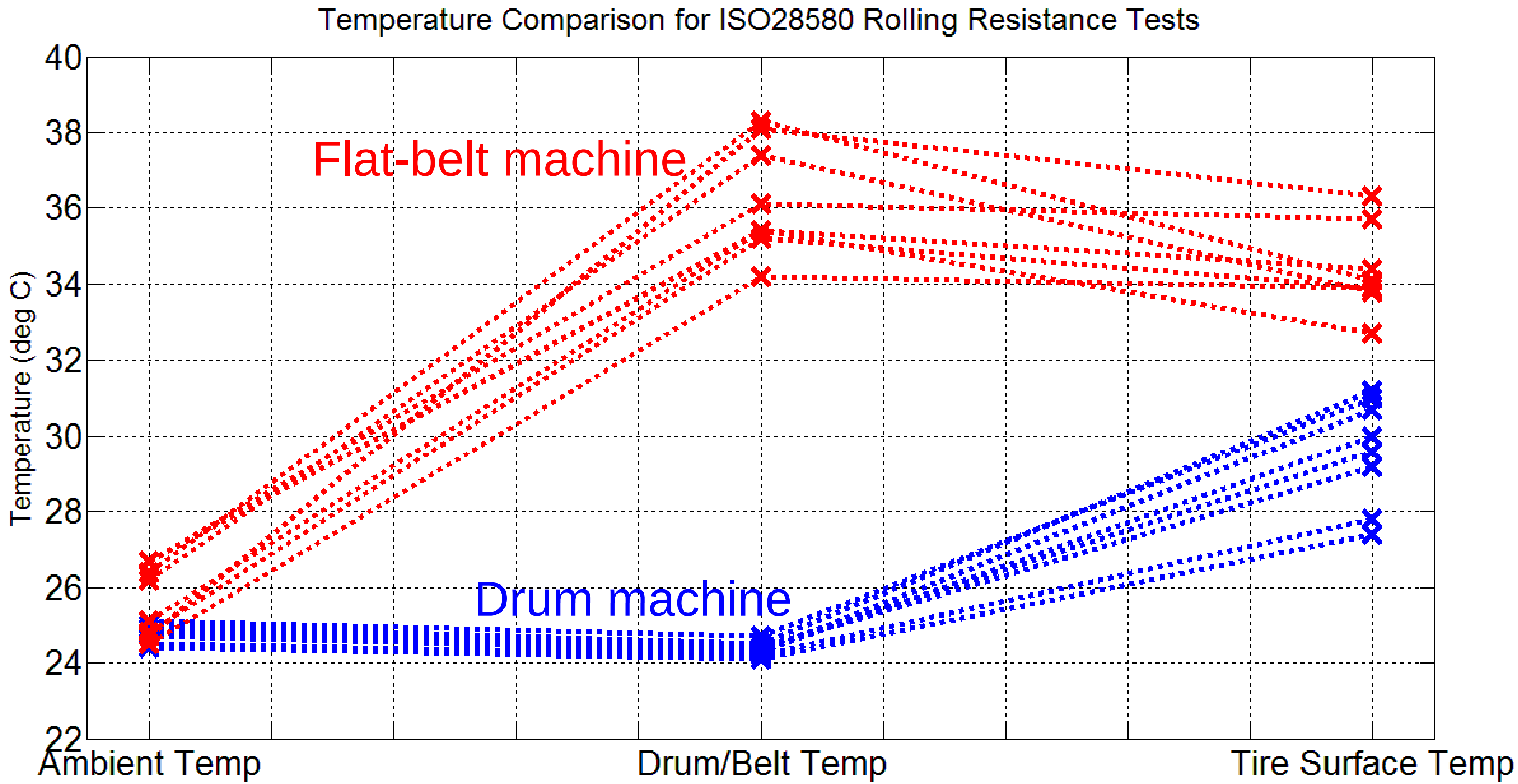
Rank Preservation

- Drum and Flat-Belt machines rank tires differently
- Flat-Belt results are lower than drum and curvature corrected [3, 5] drum machine results



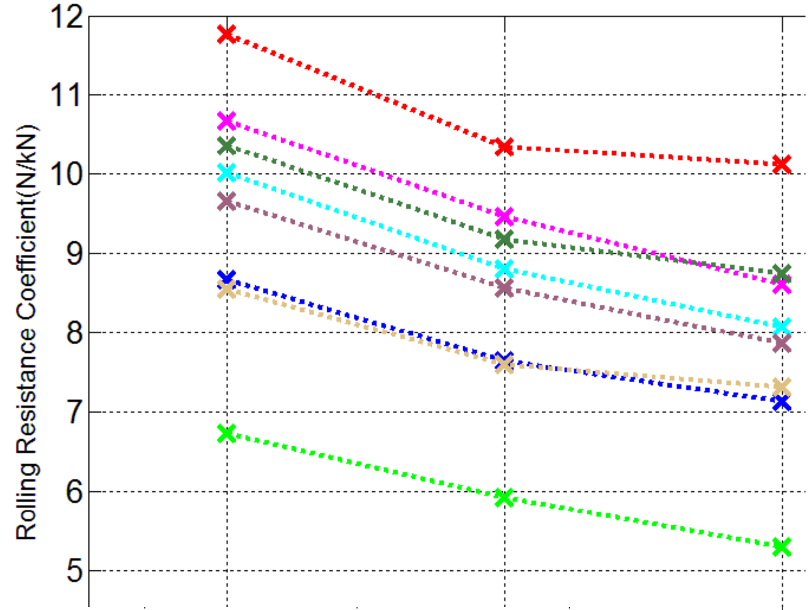
Temperature Differences

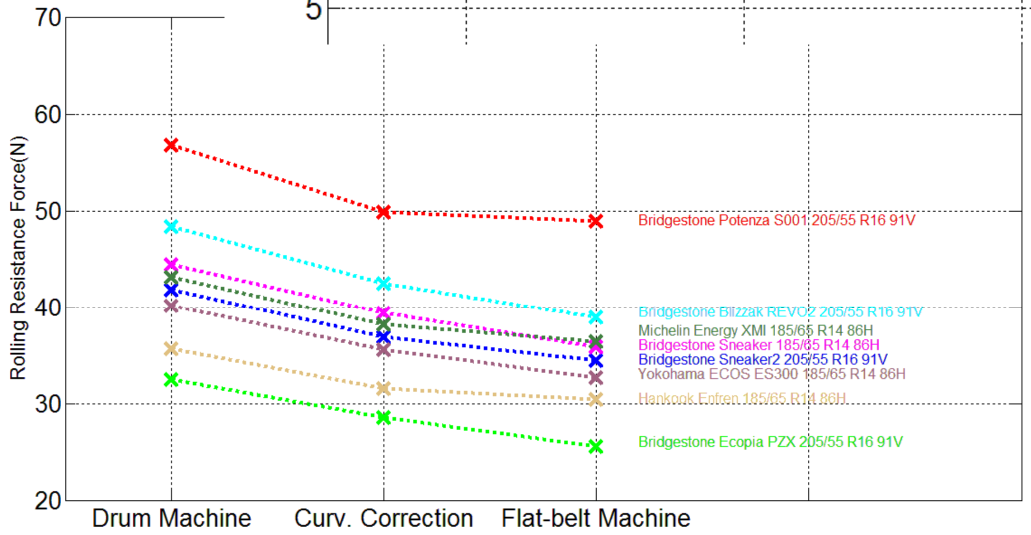
Drum acts as a heat sink whereas belt gets heated up



RRF vs RRC

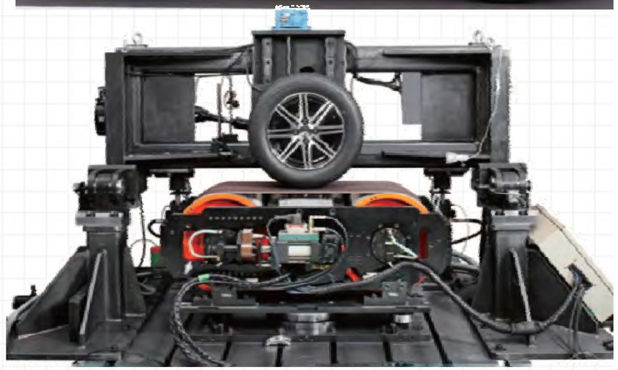
- Relative ranking is not preserved for both RRF and RRC
- Ranking based on RRC and RRF will be different as they represent different things





Summary

- Repeatable on-road measurements are possible
- Indoor measurements offer superior control of test parameters and very high repeatability
- Measured losses are significantly less than what we see on the real road
- In door testing should include more test variables (such as camber, toe, slip, etc.) to get a closer approximation of in-vehicle & on-road tire performance
- Relative tire rankings from drum and flat-belt measurements are not necessarily equivalent



Acknowledgements

- On-road data acquisition:
  - Takayasu Sasaki
  - Yuuki Sakurai
  - Masaaki Banno
  - Hiroki Yamaguchi
- Indoor data acquisition:
  - Atsuo Murakami
  - Tomikazu Oyama
  - Masaki Takahashi
- Kenji Sato, A&D Company, Japan
- Dr. Rahul Ahlawat

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