A pedaling force vector can be represented by the sum of three elemental force vector waveforms.

T. Kitawaki[1], M. Yoshida[2], R. Koyama[3], T. Usui[3], R. Tanaka[3], K. Oouchi[3], H. Takada[3] & Y. Nakamura[3].

[1] Department of Mathematics, Kansai Medical University, Osaka, Japan,

[2] Faculty of Biomedical Engineering, Osaka Electro-Communication University, Osaka, Japan.

[3] R&D Team, Lifestyle Gear Division, Shimano Inc., Osaka, Japan

Science & Cycling 2018

Conflict of Interest (COI) Disclosure

This study was a collaborative research between academia and industry funded by Shimano Inc. .

Presenting author: Tomoki Kitawaki

Introduction : Background

- Measurement of pedaling force vectors

(1) cycle trainer

pedaling analyzer

(Bikefitting.com)

(2) pedal crank

pedaling monitor

(Pioneer)

(3) pedal

P1 Pedal Power Meter

(Powertap)

Pedaling force vector
tangential direction, radial direction

Introduction: indexes of pedaling

Torque effectiveness (TE)

$$TE = \frac{(P_+ + P_-)}{P_+}$$

Pedal Smoothness (PS)

$$PS = \frac{P_{avg}}{P_{max}}$$

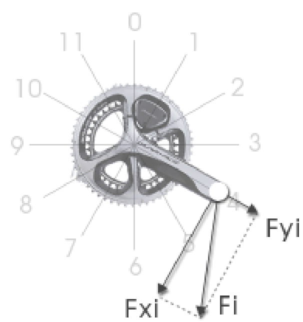
Requires force profile

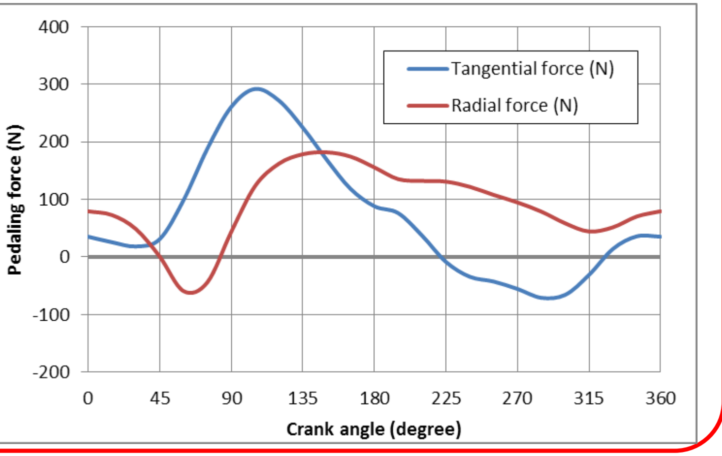
Gross Power Released (GPR)
Gross Power Absorbed (GPA)
Kurtotic Index (KI)

Efficiency Index (EI) :

$$\text{Efficiency index} = \frac{\sum_i Fx_i}{\sum_i \sqrt{Fx_i^2 + Fy_i^2}}$$

Requires pedaling force vector
Fx_i : tangential direction
Fy_i : radial direction
i : direction number

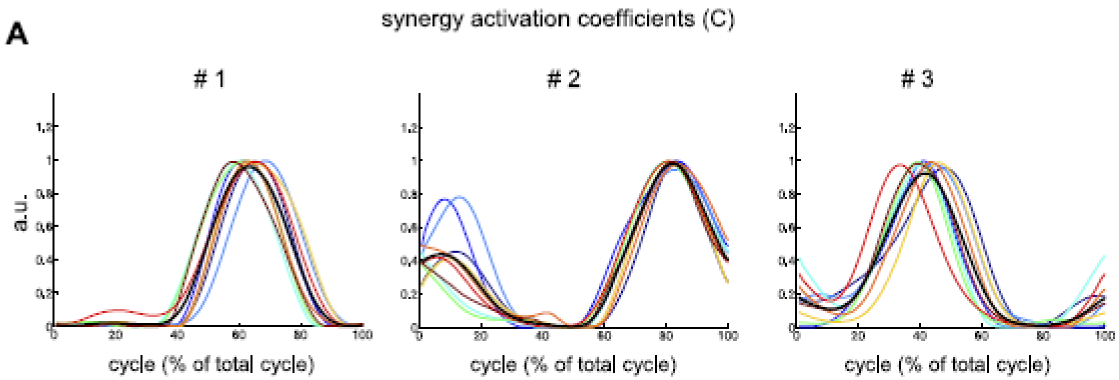




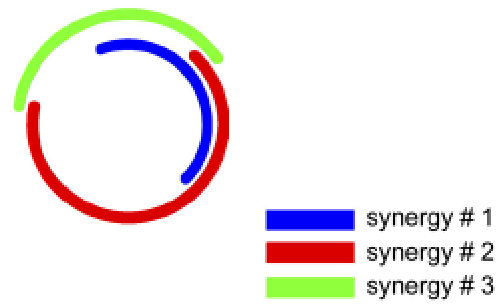
- **Mechanical pedaling characteristics can be calculated.**
- **These indicators are <u>not</u> based on body movement.**

Introduction : Purpose

A previous study:



schematic representation of the 3 muscle synergies



EMG signals of the lower limb muscles demonstrated that pedaling is accomplished by combining <u>three similar muscle synergies</u>.

(Hug F., Turpin N., Guével A. and Dorel S., J Appl Physiol, 108(6) 1727-36. 2010)

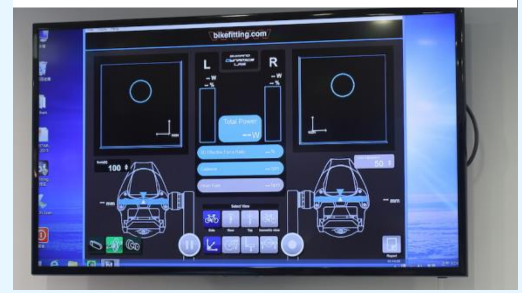
Purpose:

- To analyze the pedaling force vector waveform based on <u>biomechanical pedaling motion.</u>
- Plot the pedal force vector waveform resulting from the sum of elemental force vector waveforms.

Methods: measuring system

pedaling analyzer system (Bikefitting.com)

cycle computer unit



load device control by cycle computer

pedaling analyzer sensor unit

Pedaling force vector data was obtained every 15 degrees

Pedaling force can be obtain using the tangential and radial direction

Methods: procedure & data analysis

Procedure:

- Two participants (No. 1: former professional, No. 2: top-level amateur cyclist)
- Load power : 100, 200, 300 W
- Cadence : 70, 90, 110 rpm

} 200 W and 90 rpm set as reference value

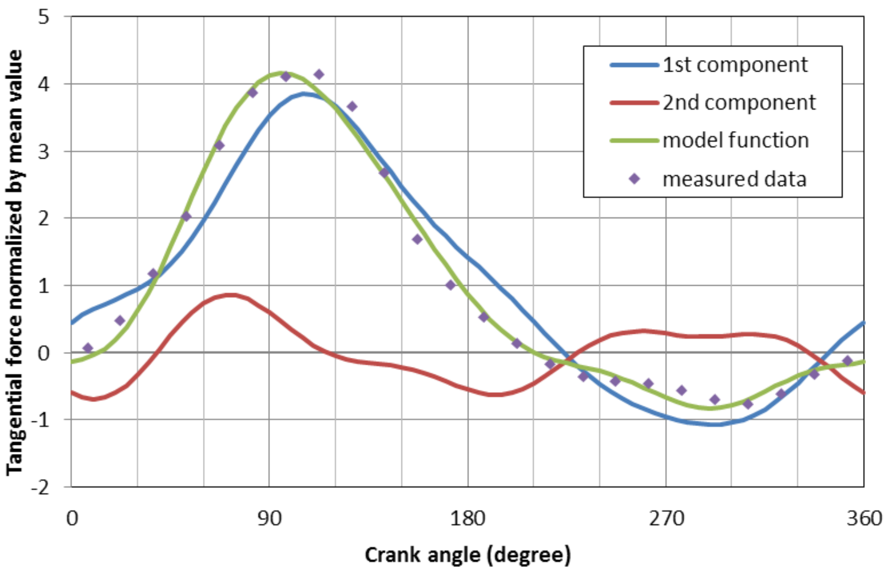
- Pedaling action : normal, spinning, pulling, and pushing and pulling
- Saddle position: back (5 mm) forward (10 mm), up (3 mm) down (5, 10 mm)

Data analysis:

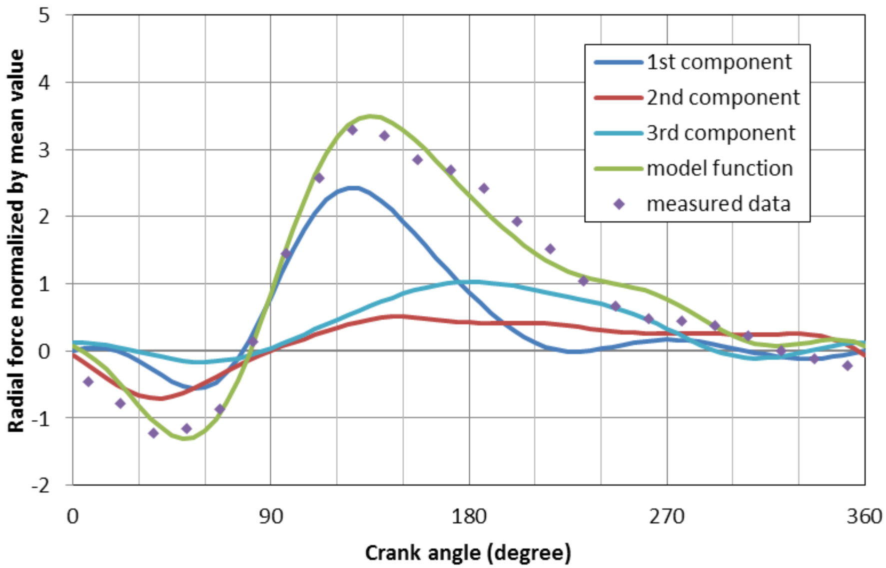
- Pedaling force vector was averaged at each pedaling condition for *60 s*.
- Pedaling vector data were expressed as the sum of several elemental vectors.
    - Common elemental vector waveforms and parameters were determined
    - RMS error between the sum of the elemental vector waveforms and the original vector data was minimized
    - Amplitude and phase angle differences were changed
    - The pedaling vector data and parameters were plotted

Results: force vector resolution (example)

tangential direction



radial direction



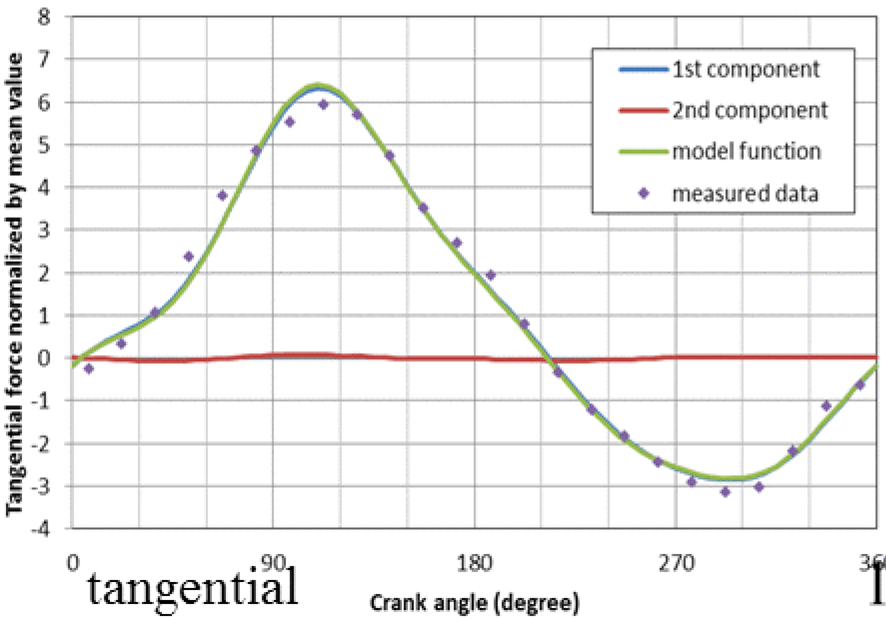
No. 2: 200 W 90 rpm

$$Tan(\theta) = T_0 \{1 + A_1 f_1(\theta - \theta_1) + A_2 f_2(\theta - \theta_2)\}$$

$$Rad(\theta) = T_0 \{B_0 + B_1 g_1(\theta - \varphi_1) + B_2 g_2(\theta - \varphi_2) + B_3 g_3(\theta - \varphi_3)\}$$

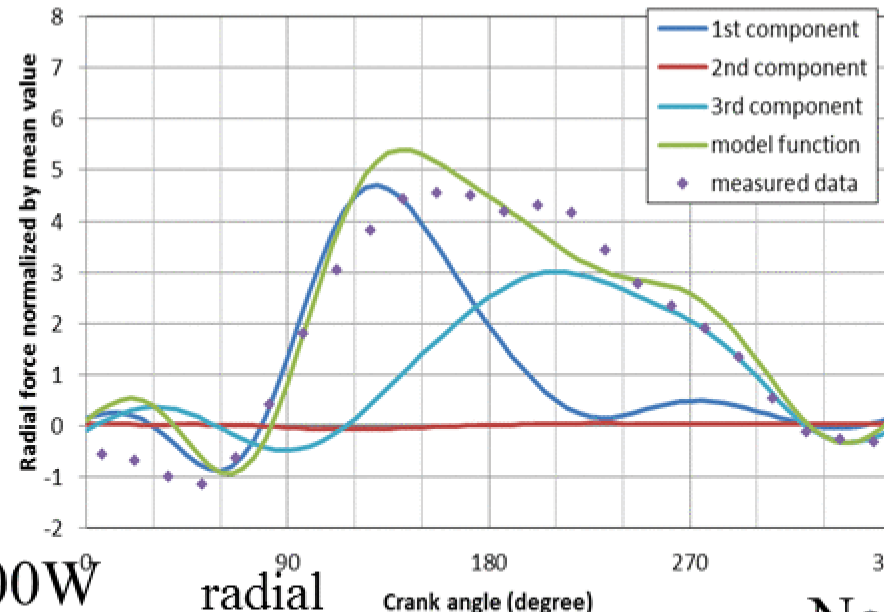
- **Tangential : sum of two waveform components**
- **Radial : sum of three waveforms**

Results: force vector resolution (power & cadence)



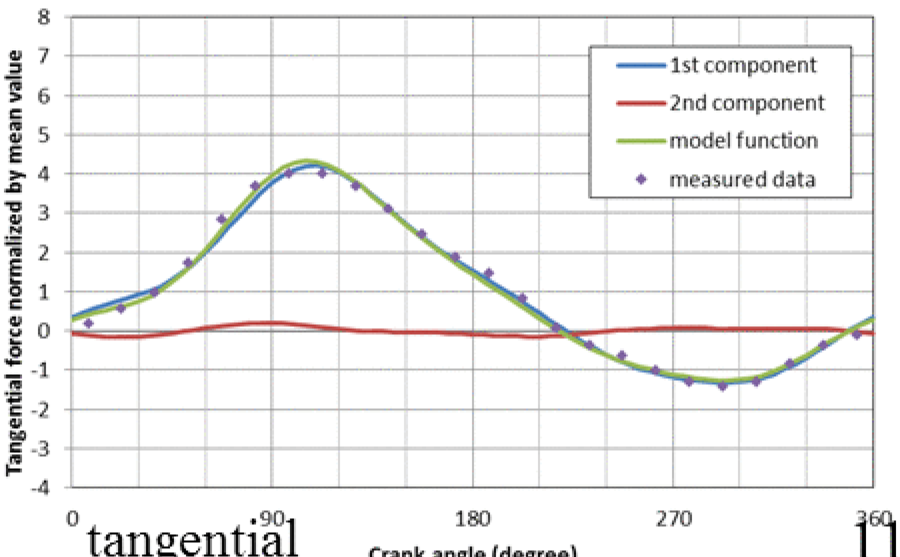
tangential

100W



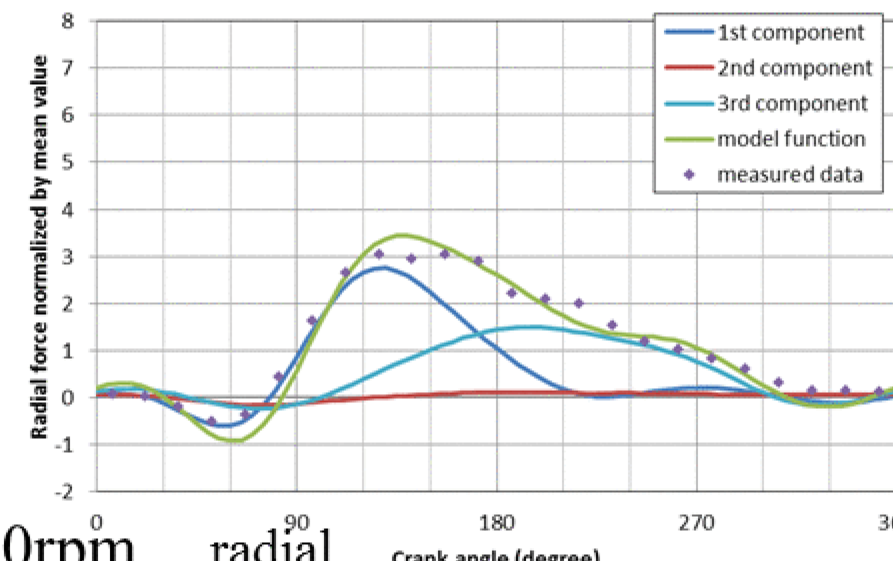
radial

No.2



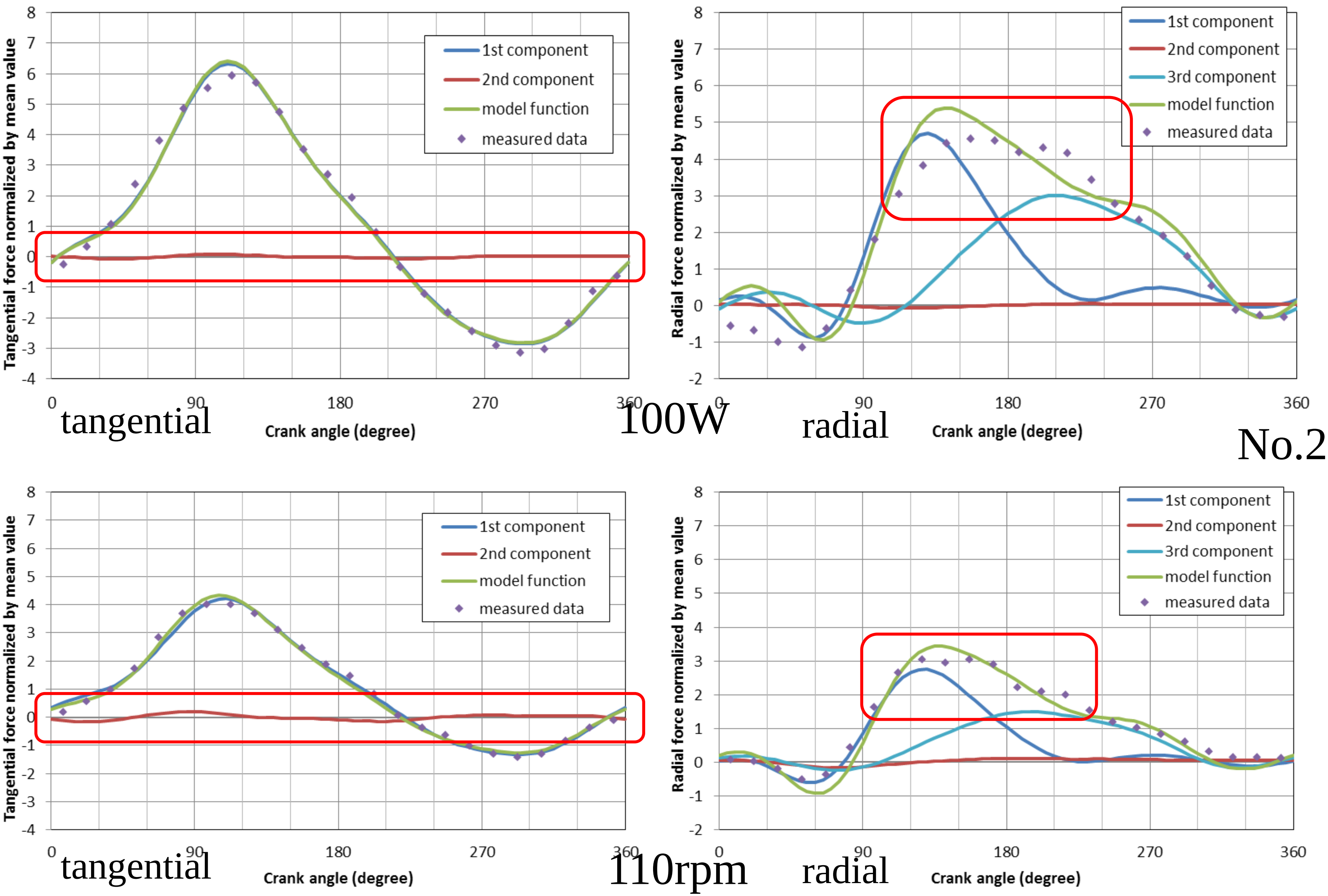
tangential

110rpm

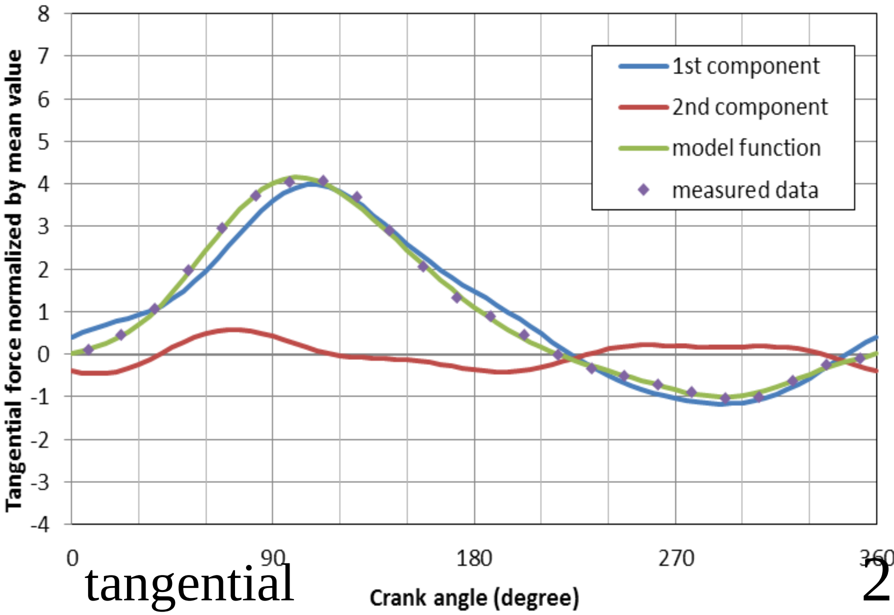


radial

Results: force vector resolution (power & cadence)

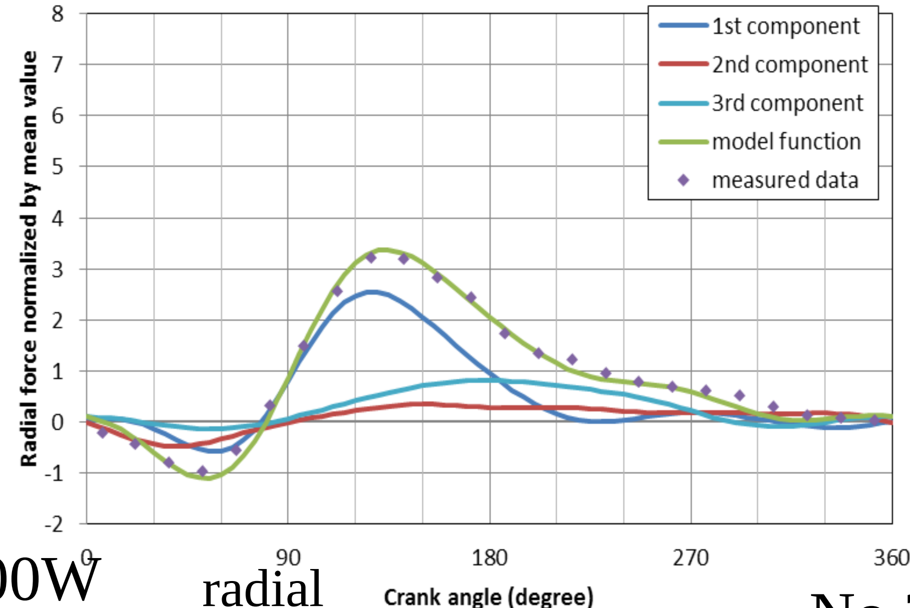


Results: force vector resolution (power & cadence)



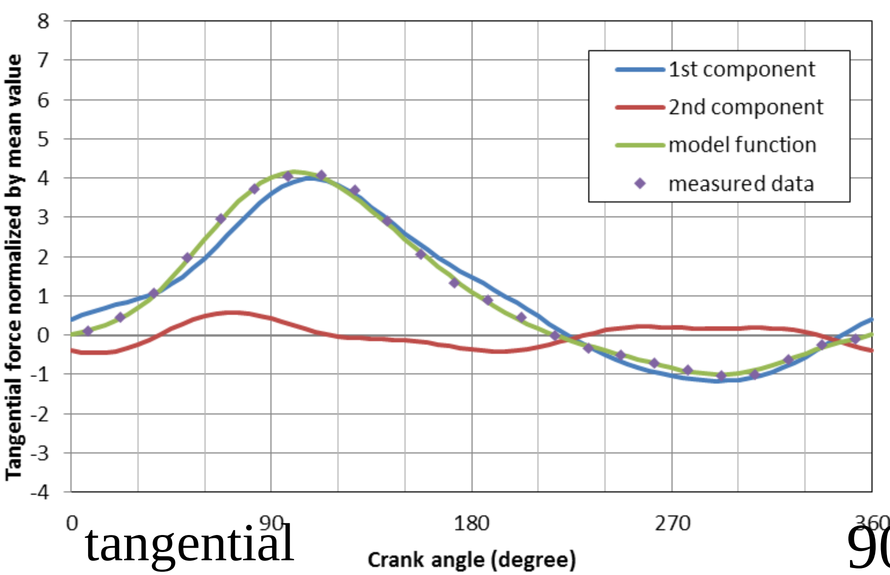
tangential

200W



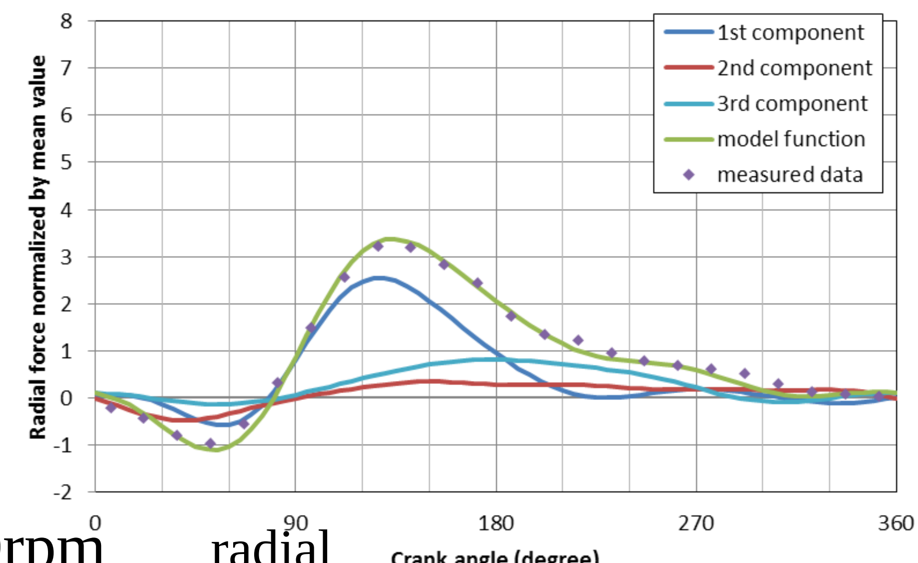
radial

No.2



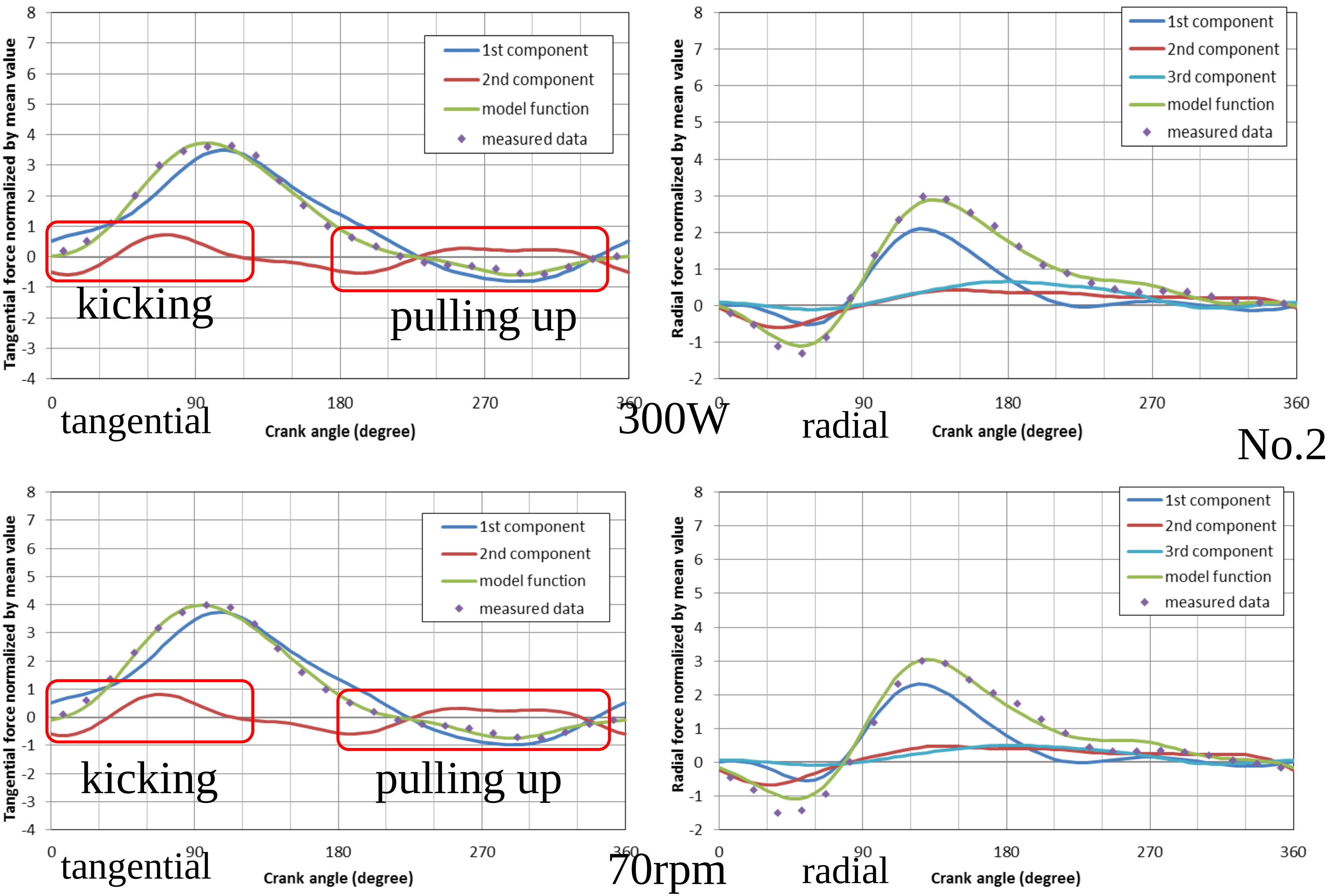
tangential

90rpm

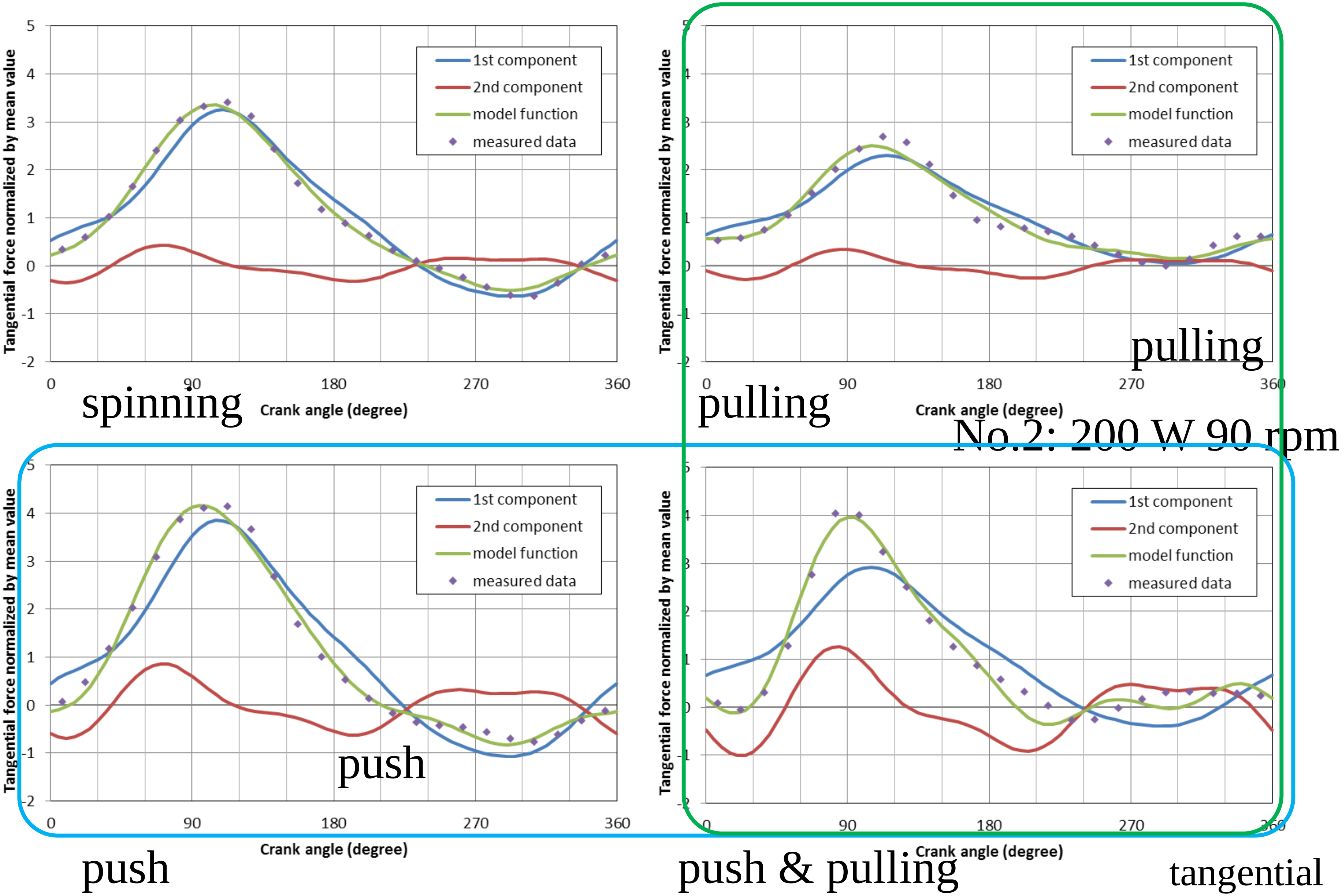


radial

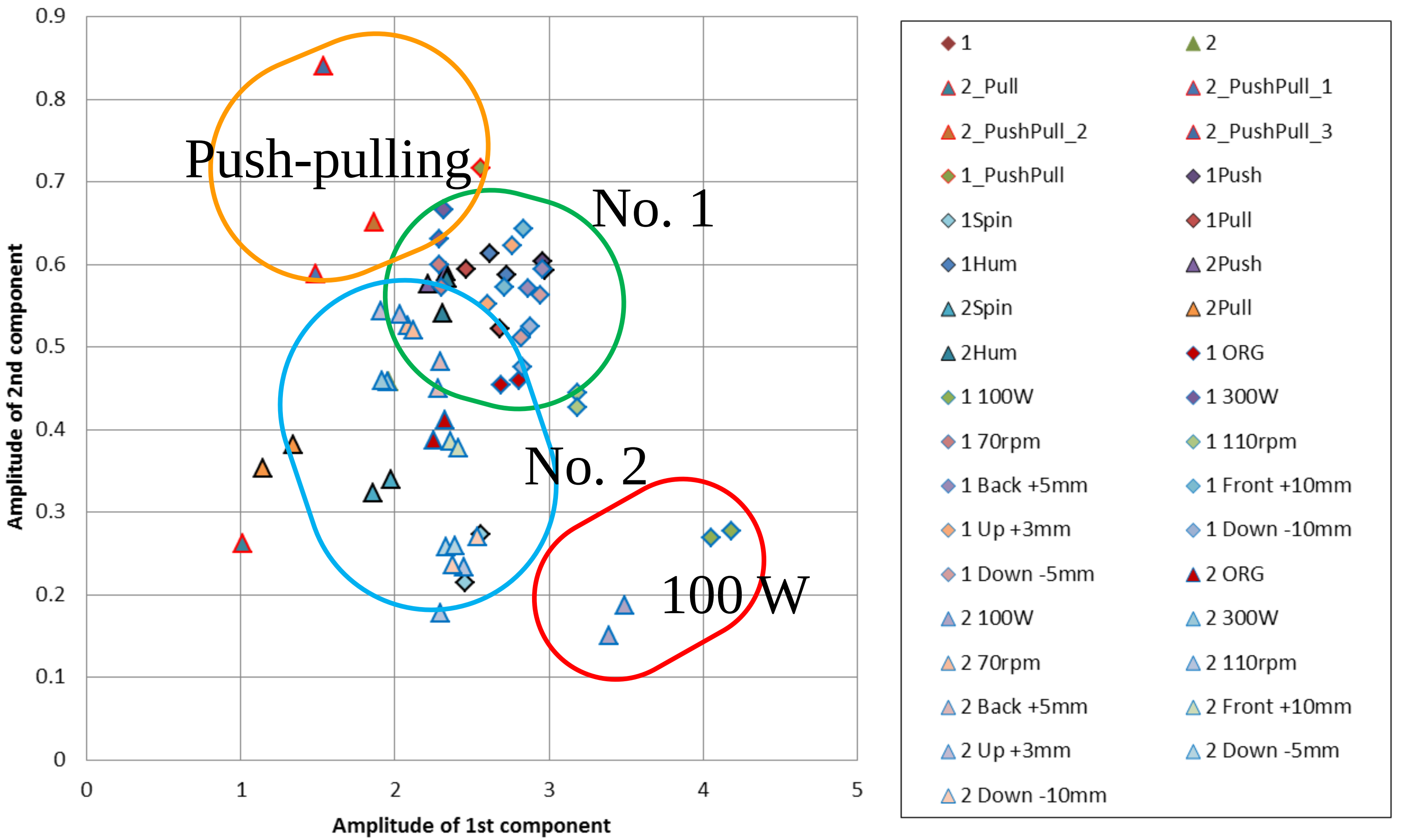
Results: force vector resolution (power & cadence)



Results: force vector resolution (pedaling action)

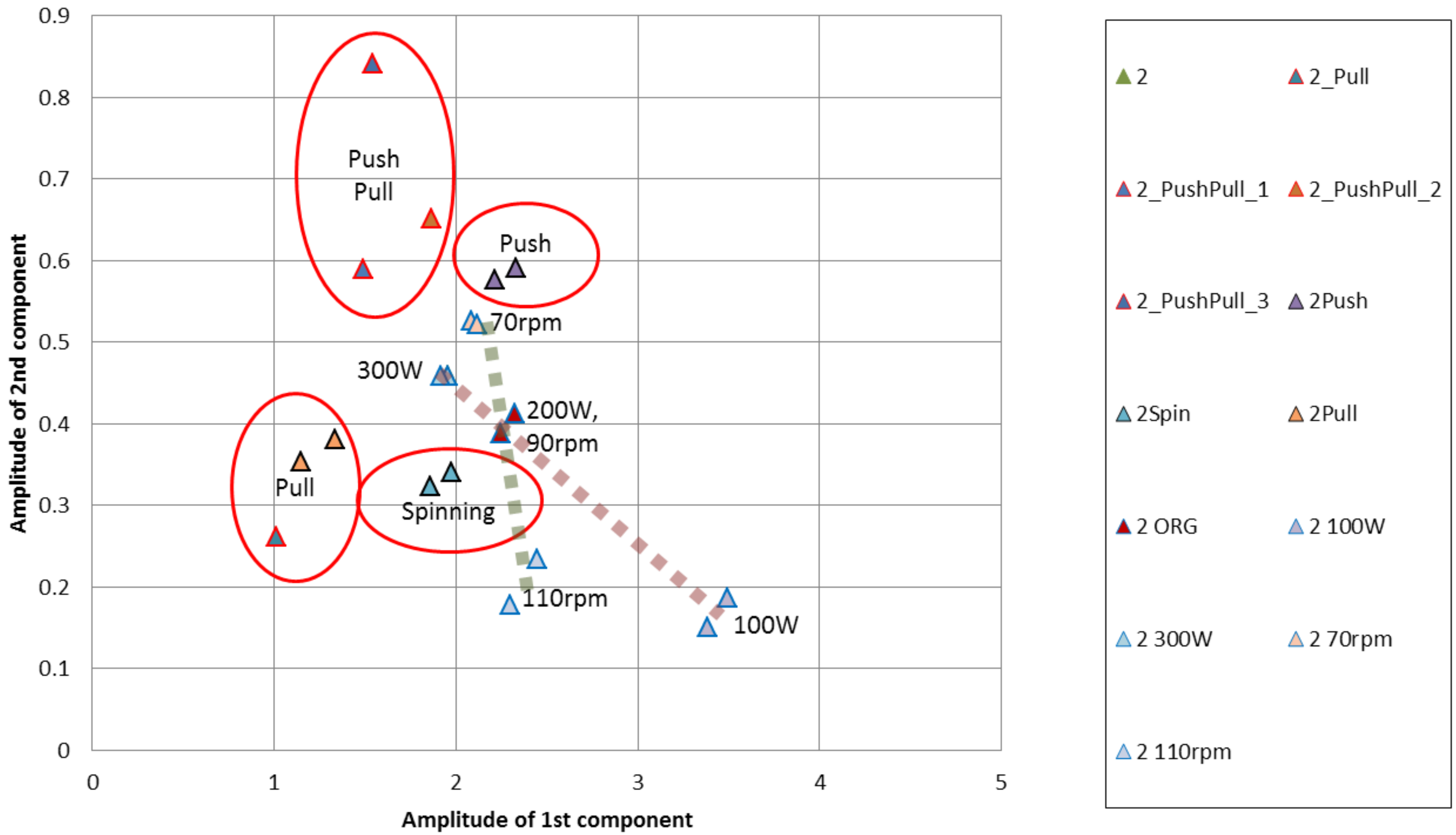


Results: amplitudes scatter diagram of components



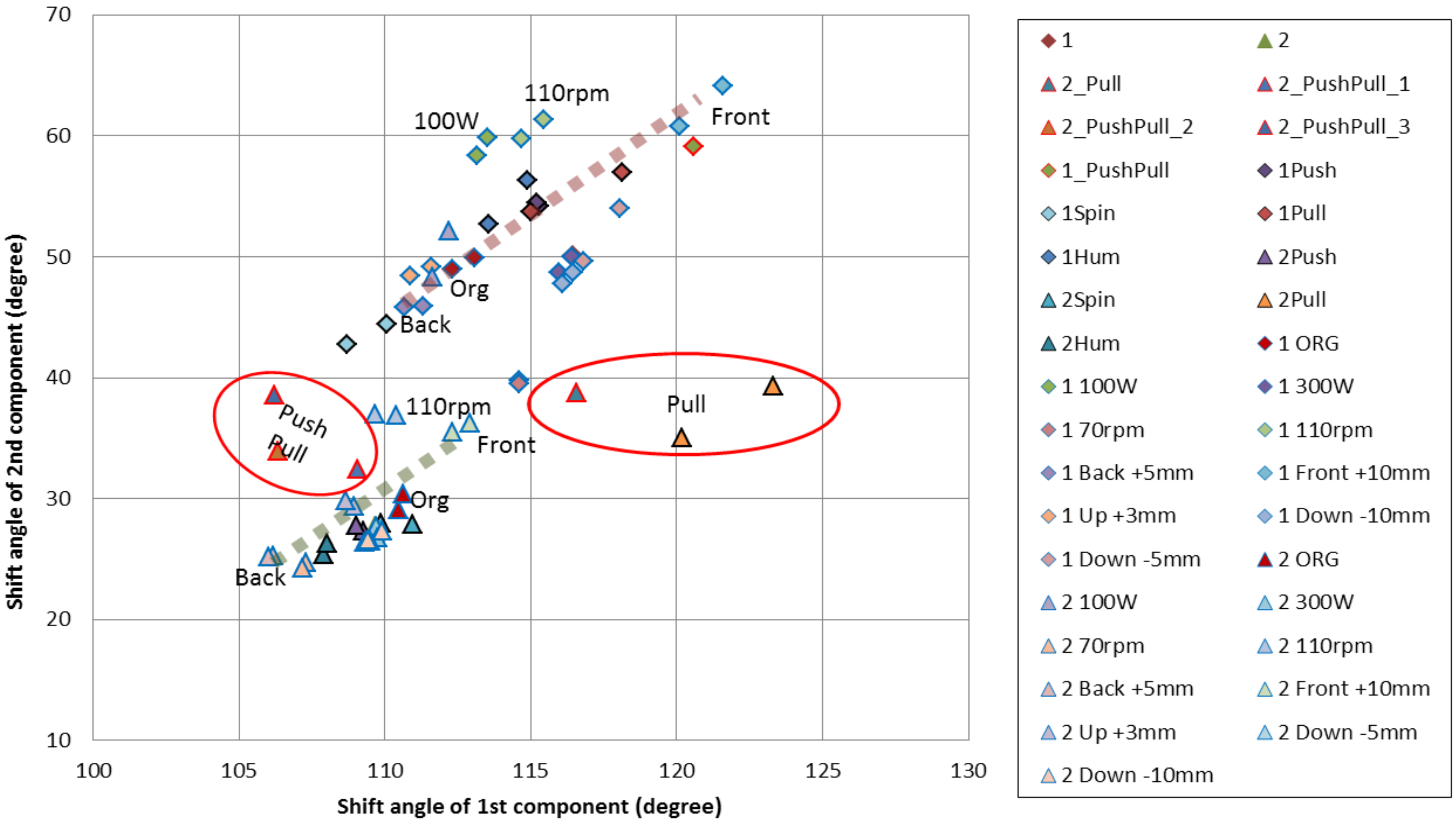
- Using this scatter diagram, it is possible to **classify pedaling characteristics.**

Results: amplitudes scatter diagram of components



- Amplitude difference appears when power and cadence change.
- Peculiar change appears when the pedaling action is different.

Results: phase angle scatter diagram of components



- Pedaling action : phase angle of the 1st component changes
- Saddle position : phase angle of both components changes simultaneously

Conclusion:

- To analyze the pedaling force vector waveform based on biomechanical pedaling motion
- The pedal force vector waveform by the sum of elemental force vector waveforms.

As a result, the following became clear:

- The pedaling force vector components (tangential: 2 and radial: 3) was represented by the sum of the elemental waveform components.
- This force may corresponds to the muscle behavior expressed by three synergies.
- This study accounted for both of the waveform's amplitude & phase angle change.

Future:

- Investigate the difference between changes in the element waveform and the muscle force assessment.
- Study the corresponding muscle force strength and pedaling action.

e-mail： kitawaki@kmu.ac.jp

Thank you for your attention.