Project 003: Considerations about "Dead Centre" in cycling.

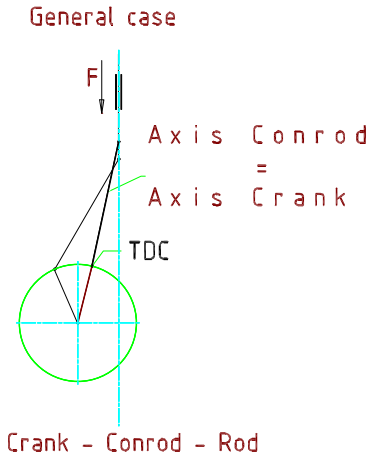
In bicycle pedalling, the pedal crank cycle is characterized by a power phase (pedal down-stroke) followed by a recovery phase (pedal up-stroke).
Scientific and other publications introduce the notion of "Dead Centre" (or "Dead Spot" or "Dead Point"), separating the "power phase" from the "recovery phase" and being **arbitrary** located at 0° (Top-Dead-Centre or TDC) respectively at 180° (Bottom-Dead-Centre or BDC). In this position the cranks are vertically positioned.

Many authors try to explain possible biomechanical advantages of the non-circular chainring by the effect of the reduced immediate gear ratio making the crank arm pass through these "idle zones" faster (what happens when the crank arm is oriented roughly in line with the minor axis of the oval).

The question is:
-what is the exact meaning of the "Dead Centre" in the bicycle pedalling cycle?
-where is or are the "Dead Centre(s)" located?

1. Definition of "Dead Centre"

In mechanical engineering, by describing a crank-conrod-rod mechanism (see a 2-stroke engine) the notion of "Dead Centre" is meaningful and is perfectly defined. See picture 1.



Picture 1: Crank-conrod-rod

In the crank - conrod - rod mechanism, the rod is the driving element. The force F in the direction of the rod is transferred to the crank by means of the connecting rod (conrod).
The joints of the bars are perfect pivot points. The crank will rotate when the pivot point of the joint "crank-conrod" is not positioned in a "dead centre". The drive system arrives in a "dead centre" when the axis of the crank is located along (is in line with) the axis of the conrod.
More general, the dead centre is any position where the driving force in the direction of the conrod passes straight through the crank axis.
In such a "dead"- position the angular velocity of the conrod equals zero and the crank power is zero too.
In most cases, the axis of the rod goes through the centre of the crank-axle. If in such a configuration the direction of the rod is vertical, then the Top-Dead-Centre is located at 0° and the Bottom-Dead-Centre is at 180° (rotation: counter clockwise).

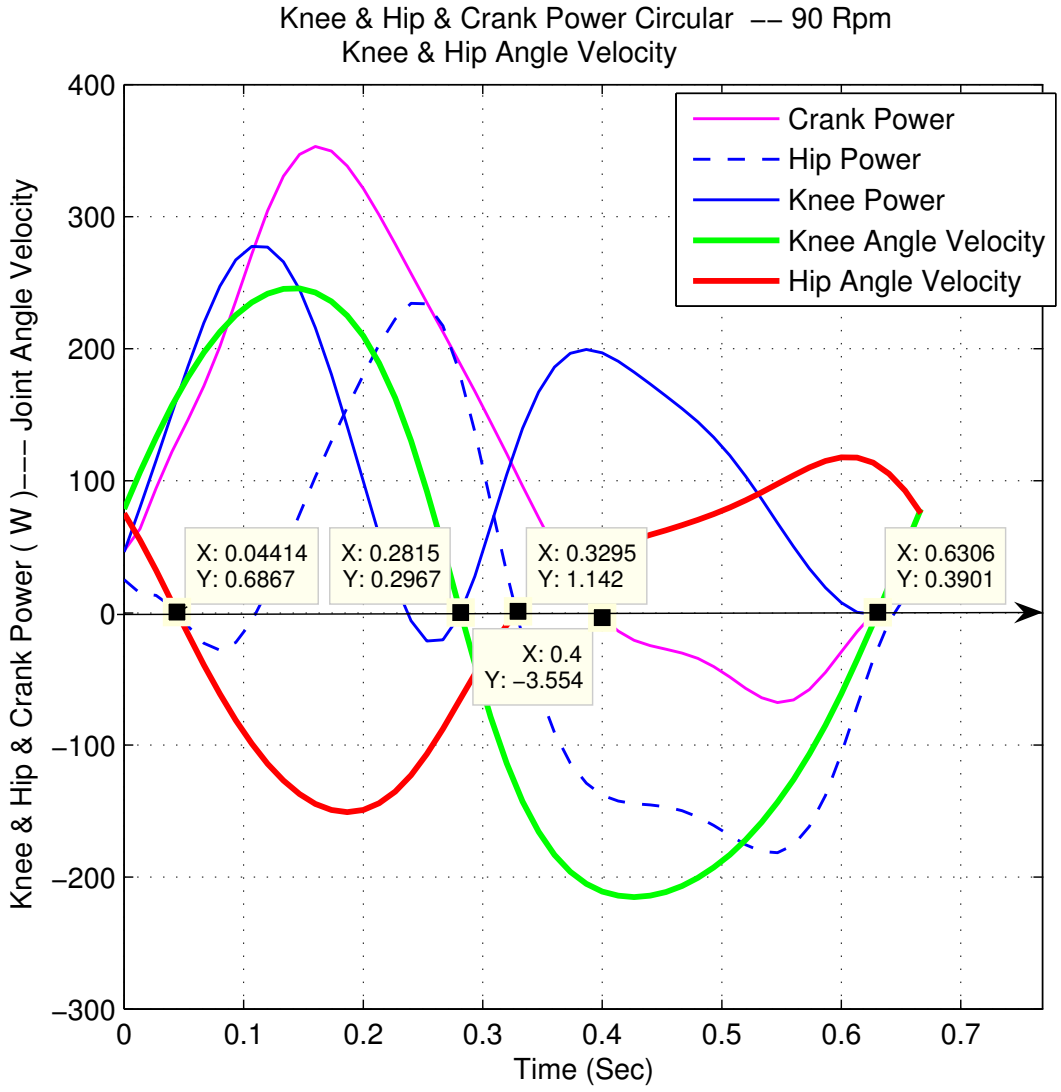
2. Dead Centre in the bicycle drive system.

To the authors' knowledge, "all" the publications and studies handling the bicycle drive system locate the Dead Centres of the pedal crank cycle at 0° respectively 180°.
This is a purely **arbitrary** definition.
Indeed, the bicycle drive system is a five-bar mechanism.
Three of the four rotation points are not perfect pivot points but actuators: the ankle joint, the knee joint and the hip joint.

If any, where are the Dead Centres located in the bicycle drive system?

We learned that, in the crank - conrod - rod mechanism, the Dead Centres occur at the moment of time when the conrod angular velocity equals zero. Then, the crank power is zero too.
By analogy with the crank - conrod - rod mechanism **we may assume the Dead Centres of the knee joint occurring at the points in time when the knee angular velocity equals zero**, consequently where the angular velocity changes from positive to negative or where the flexor muscles activity switches over to extensor muscles activity (or vice versa).
The same may be assumed for the hip joint and also for the ankle joint.

By means of the biomechanical model (MATLAB® software) the knee angular velocity, the hip angular velocity, the knee power, the hip power and the crank power were calculated throughout a full crank revolution for a **circular chainring** and presented in graph 1.



Graph 1

Data-tips indicate when the joint angular velocities equal zero.

Graph 1 is applicable in the case of a crank arm length of 0.17 m, a seat height of 0.713 m (centre of the bottom bracket to the top of the saddle) and a seat tube angle of 73.0°. The pedalling frequency is 90 rpm.

Arguing the Dead Centres of the joints occur at the point in time when the respectively joint angular velocities equal zero leads to the conclusions:

For the knee joint:

- Top-Dead-Centre at 0.6306 sec cycle time = - 20° crank angle (or +340°)
- Bottom-Dead-Centre at 0.2815 sec cycle time = +152° crank angle

For the hip joint:

- Top-Dead-Centre at 0.0441 sec cycle time = + 24° crank angle
- Bottom-Dead-Centre at 0.3295 sec cycle time = +178° crank angle

As a consequence for a **non-circular chainring**,
in order to have the knee joint "pass fast" trough the T-D-C, the minor axis of the oval (is also the smallest radius of the chainring) has to be vertical when the crank is located at -20°.
This positioning of the crank versus the non-circular chainring is compatible with the conclusions about optimal crank orientation put forward in the "Comparative biomechanical study of circular and non-circular chainrings for endurance cycling at constant speed" .

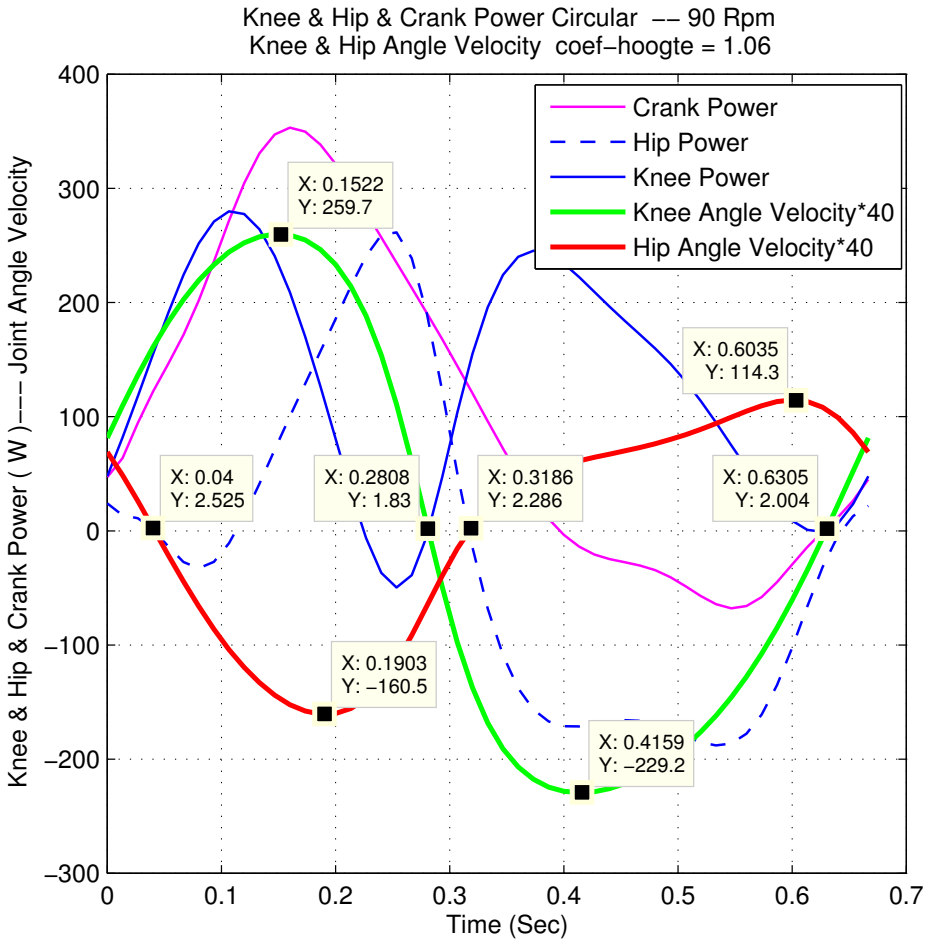
The location of the Dead Centres is not dependent on the shape nor on the crank orientation of the non-circular chainring. Indeed, the spindle of the pedal always traces a circular path.
The location of the Dead Centres are a (weak) function of the anthropometric parameters (length of the limbs) and of the bicycle geometry (seat height, crank arm length and seat tube angle).

3. The impact of changes in bike geometry on the Dead Centre location.

In the graphs 2 and 3 below the location of the Dead Centers is calculated by changing the seat height and the crank arm length.

Graph 2: seat height 0.733 m (in stead of 0.713 m)

Crank arm length 0.17 m, seat tube angle 73°, limb data unchanged



Graph 2

Location of the Dead Centres is:
for the knee joint:

- Top-Dead-Centre at 0.6305 sec cycle time = - 19.5° crank angle (or +340.5°)
- Bottom-Dead-Centre at 0.2808 sec cycle time = +151.6° crank angle

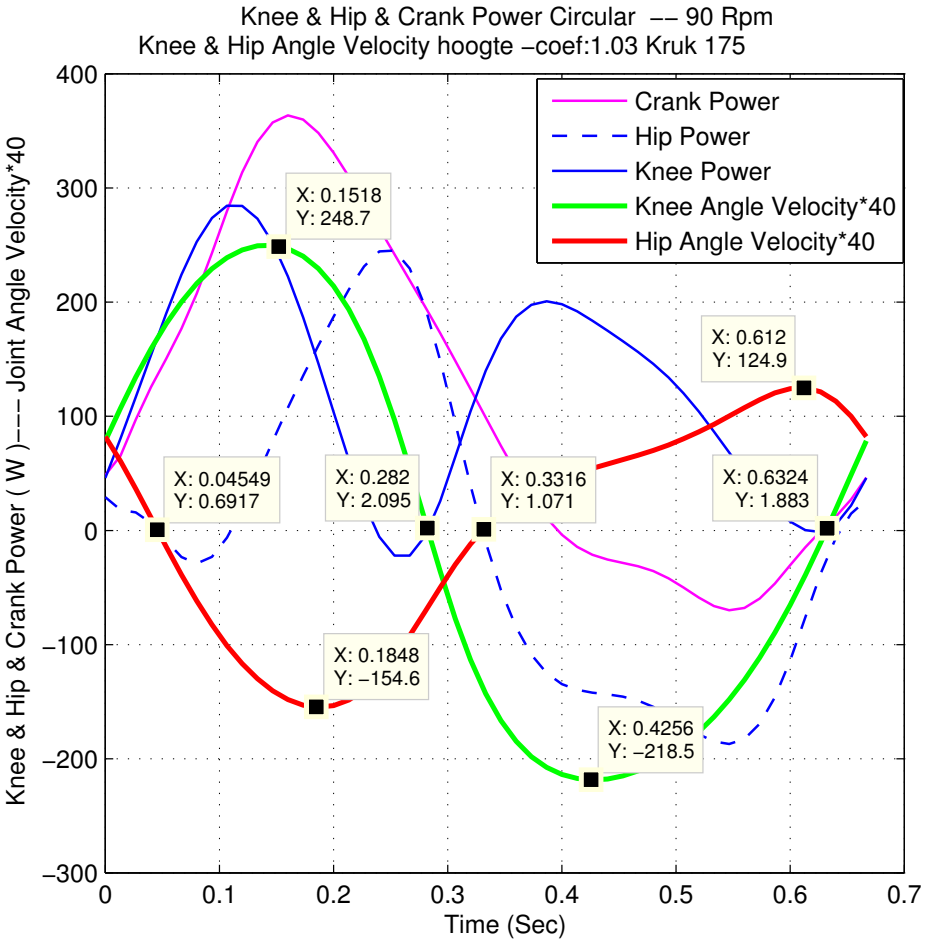
for the hip joint:

- Top-Dead-Centre at 0.0400 sec cycle time = + 21.6° crank angle
- Bottom-Dead-Centre at 0.3186 sec cycle time = +172° crank angle

The impact of the seat height parameter is relatively small specifically for the knee joint.

Graph 3: crank arm length 0.175 m (in stead of 0.17 m)

Seat height 0.713 m, seat tube angle 73°, limb data unchanged.



Location of the Dead Centres is:
for the knee joint:

- Top-Dead-Centre at 0.6324 sec cycle time = - 18.5° crank angle (or +341.5°)
- Bottom-Dead-Centre at 0.282 sec cycle time = +152.3° crank angle

for the hip joint:

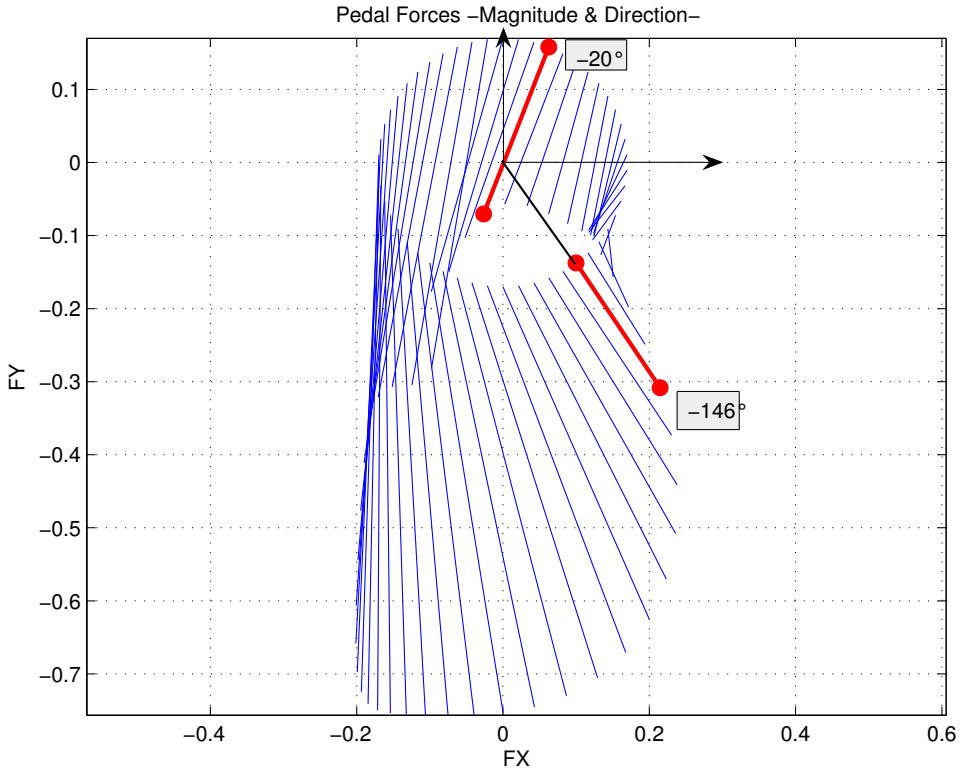
- Top-Dead-Centre at 0.0455 sec cycle time = + 24.6° crank angle
- Bottom-Dead-Centre at 0.3316 sec cycle time = +179° crank angle

The impact of the crank arm length parameter is relatively small for the knee joint. For the hip joint the impact is more substantial.

4. Location of Dead Centres based on Pedal Force Vector

It is also possible to define the location of the Dead Centres, based on measurements of the pedal force components.
The Dead Centres are located where the direction of the Pedal Force Vector goes through the centre of the bottom bracket.

Graph 4 shows the pedal forces (scaled), measured and published by professor Hull et all. These data have been used in the study "Comparative biomechanical study of circular and non-circular chainrings for endurance cycling at constant speed" .
In this approach, the location of the Dead Centres is strongly influenced by the pedalling technique.
The location of the knee joint Dead Centres defined via Pedal Force Vector considerations matches remarkably with the Dead Centre locations derived from the evolution of the joint angular velocity during a pedal cycle.



Graph 4