KINEMATIC SEQUENCE - CALCULATION METHODS

Comparison of Kinematic Sequence and Kinetic Link

Firstly a little background; Phil Cheetham in collaboration with Greg Rose and the TPI Biomechanics Board of Advisors developed the version of the kinematic sequence method now used by TPI, AMM and KMI; Chris Welch developed the version of the kinetic link method used in the Zenolink analysis. Here we will look at these two different ways to calculate the angular velocities of the body segments during the golf swing. Both these methods display how a skilled athletic motion can efficiently make an end body segment or implement move very fast, as in hitting, kicking or throwing. This principle has been generically called "proximal to distal sequencing" and can be described in several ways; as joint angular velocities, as segmental angular velocities and as joint torques, to name just a few. If joint torques and forces are used it probably should be termed "kinetic"; if angular velocities are used it should be termed "kinematic". Why? Well here's a quick definition of these two terms:

- Kinematics is the study of motion without regard to the forces producing the motion; parameters such as position, angle, velocities and accelerations.
- Kinetics refers to the study of the forces and torques that create the motion.

Surprisingly, the term "kinetic link" is commonly used in biomechanics and by Zenolink, even when angular velocities are used. We chose the term kinematic sequence because we use a different set of angular velocities than Zenolink and wished to differentiate between the two methods. Let's look at these two methods in detail; it will get a little complicated but I will summarize at the end.

Kinetic Link Calculation Method:

The angular velocities for the kinetic link are calculated as follows: A pelvis origin is defined as a point mid way between the hip joints; an upper body origin is defined as a point mid way between the left and right shoulder joints; a fixed spine axis is defined as the line from the pelvis and upper body origins. A plane is produced perpendicular to the spine axis at the level of the pelvis origin; call it the "perpendicular to spine" plane (the PTS plane). A vertical plane parallel to the target line is defined to cut through the PTS plane; the line this produces on the PTS plane is used as the zero reference line. A line in the pelvis from hip joint to hip joint is projected into the PTS plane. A line in the upper body from shoulder joint to shoulder joint is projected into the PTS plane. Finally a line is created from the mid shoulder point to the mid hands on the club grip (called the "composite arm" line) and it is also projected into the PTS plane. These three lines allow a rotation angle to be calculated between each one and the zero reference line. Segmental rotation speeds are calculated as the time rate of change of these angles. This method so far allows us to calculate a rotation speed of pelvis, upper body and composite arm; backwards rotation speeds are negative and forward rotation speeds are positive. We still need and angular velocity for the club; strangely though the kinetic link method doesn't use the club speed as the forth curve; it uses the wrist release speed instead. The wrist release speed is the relative speed of the club shaft with respect to the composite arm; that is; the speed that this "joint" opens during the downswing.

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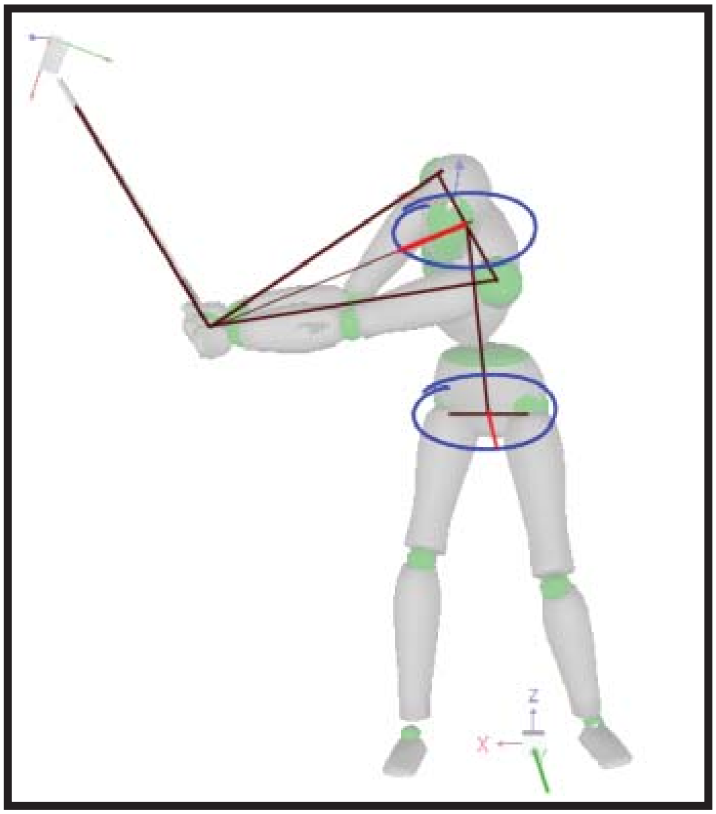
Kinetic Link Calculation Method cont.:

So the kinetic link uses three segmental angular speeds and one joint angular speed. At least the three segmental angular speeds seem intuitively good since the golf swing is usually thought of as rotating around the spine. However on closer look they suffer from out of plane errors since the segment vectors are actually projections on to the PTS plane. If any of these segments (pelvis, upper body or composite arm) tilt out of the PTS plane, that is to say, if they don't rotate exactly in a plane that is perpendicular to the spine line then angular speed errors will occur. This is especially evident with the composite arm line.



The Spine Axis Method, showing the PTS Plane.

There is another problem with this method and that is the use of the composite arm to represent the third link in the chain. This link is an combination of the motion of the upper arms and forearms of the golfer; it spans the shoulder, elbow and wrist joints; all of which are free to move independently. We at TPI found that this tends to cause this velocity to fluctuate depending on how much the golfer bends the arms and the wrists; quite often it peaks earlier than the upper body even in good golfers. Finally I emphasize that in the kinetic link method, the last link in the chain is the not the club speed but the wrist release speed.

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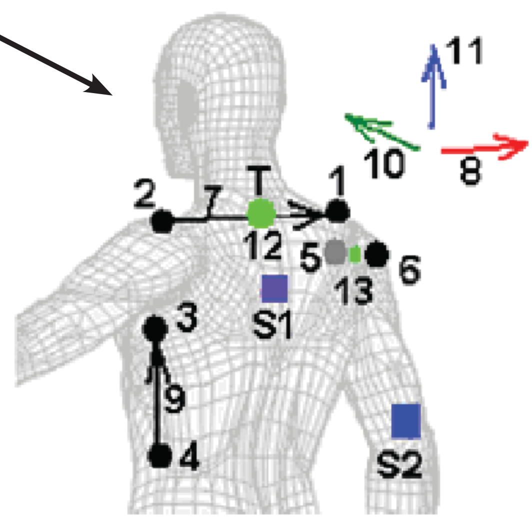
Kinematic Sequence Method - TPI 3D

The angular velocities for the kinematic sequence are calculated as follows: Anatomically based local coordinate systems are created in each body segment by digitizing specific bony landmarks; this method is also used for the club. This is a standard biomechanical practice that effectively takes a sensor that is placed anywhere on the segment and "moves" it inside the body to a specific anatomically relevant position and orientation. The external sensor data is then continuously transformed into these anatomically corrected local coordinate systems throughout data capture.

Example of the Anatomical Digitizing Method
S1 is the sensor but T becomes the local coordinate system of the thorax



The angular velocity vector of each segment's motion is then calculated with respect to the global coordinate system; in the case of an electromagnetic system this is in the middle of the transmitter on the tripod behind the golfer. This vector is then resolved into the local coordinate system of the respective body segment and broken into its coordinates around the three local axes of the segment; the inferior-superior, medial-lateral, and anterior-posterior axes. For the pelvis and thorax the angular velocity component around the inferior-superior (up-down) axis is used to represent the rotational velocity of that segment. The lead upper arm was used as the third link in the sequence because of its direct attachment to the thorax and importance in the downswing. The arm and club rotate about an end point in a pendulum motion and not around a center point; hence the angular velocity component around a normal to the instantaneous swing plane was used for these two segments; again derived in the local coordinate system of the specific segment. It is also of interest that no digital filtering was applied during the calculations because the electromagnetic hardware has a high sample rate of 240 Hz (compared to 60 Hz for NTSC video) and produced very clean position and orientation signals. Inappropriate or over smoothing will distort the timing and amplitude of peaks especially near impact.

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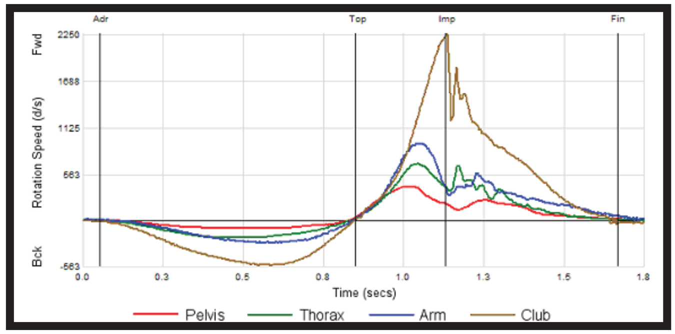
Example Kinematic Sequence Graph
Finally, the TPI 3D kinematic sequence method produces four segmental rotation speeds; pelvis and thorax around their internal anatomical up-down axes; lead upper arm and club around a normal to the instant swing plane of each. The strength of this method is that the local coordinate system of each segment moves with its segment so there are no projection or out of plane errors.



Summary

Kinetic Link

■ This method graphs the angular velocity component of each of the pelvis, upper body, and composite arm around a spine axis fixed between the pelvis and upper body segments, then it adds the wrist release angular velocity as the fourth curve; three segments plus one joint. Apples and oranges?

■ It forces the pelvis, upper body and "composite arm" to remain in a fixed plane relative to the spine axis line because it projects their lines into that plane; but in a swing they don't remain in that plane; they tilt out of this plane significantly; this will cause high or low values that don't really exist (called projection errors).

■ The use of the composite arm in this method is a problem since it is a non-rigid segment that is forced to act as if it is a rigid segment; it is not; it is altered by the motions of two shoulders and two elbows. Note that in certain cases it may still be useful if you keep these limitations in mind; AMM also uses this segment in the 4 sensor system because no arms are available; but it is better if you have arms.

Kinematic Sequence

■ This method graphs the angular velocity components of the pelvis, thorax, lead upper arm and club shaft around the appropriate local segmental axis; all four are segments; it doesn't mix segments and joints. Each component is calculated around an internal anatomical local axis that moves with the segment. This method does NOT leave the results in the world or global coordinate system.
■ The spine is not considered rigid so no out of plane errors occur.
■ The lead upper arm is used instead of the composite arm, so the action of the thorax on the arm is seen directly. Note that we can also add the lead forearm as a fifth component of the sequence if we choose; this is especially of interest when there is a bend of the leading arm.